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Volume VI

MATERIALS SCIENCES & MANUFACTURING

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PREFACE

January 15, 1971

The eight volume preliminary edition of this publication, "Reference Earth Orbital Research and Applications Investigations" (NHB 7150.1), has been produced under the guidance of discipline oriented Review Panels at NASA Headquarters and at the various NASA Field Centers. The bases for the data collected and set forth in these eight volumes have been studies performed under contract and in-house over the past few years in an effort to identify and characterize the requirements for scientific and applications activities in an earth orbital facility. The data have been organized primarily by scientific or technical disciplines and they provide a means of comparing weights, power requirements, usefulness, operational requirements and constraints, and other useful design elements.

The present approach has been adopted to provide an organized and uniform means of defining the various types of experimental, operational, or demonstration facilities which will serve each major discipline area. The data are intended to relate to Space Station, Research and Application Modules, and to the Space Shuttle in such a way as to permit a flexible, multidisciplinary space capability. The experiments and operations described herein serve to point out the role of man in typical "reference" research and applications programs. It is hoped that this publication will assist in the formulation of a rationale for defining requirements for an earth orbital research capability of great use and flexibility.

The research and applications investigations described in these volumes were designed to avoid a heterogeneous collection of individual experiments and are aimed at a "research facility" and "module" approach. The term Functional Program Element (FPE) and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complete module but would, however, permit flexibility in planning experiments which are compatible or non-interfering. Thus, the term "Functional Program Element" (FPE) describes a grouping of experiments characterized by the following two dominant features:

a. Individual experiments which support a particular disciplinary area of research or investigation; and

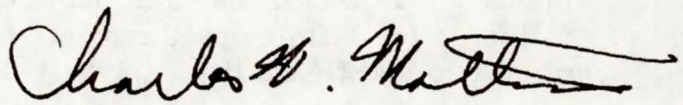
b. Experiments that impose similar and related demands on the Space Station, Shuttle or Support Systems.

Functional Program Elements and experiments described are candidates for flight with either the initial Space Station or Research and Applications Modules (RAM) supported by the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be candidates during the early years of the Space Station and Space Shuttle have been described in detail. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended when additional requirements are identified or when greater capabilities are needed. This document not only revises and updates the experiment programs but also considers the Space Shuttle as well as the Space Station requirements. The earlier versions of the "Blue Book" are hereby voided.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II through VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary	Volume VI	Materials Science and Manufacturing
Volume II	Astronomy		
Volume III	Physics	Volume VII	Technology
Volume IV	Earth Observations	Volume VIII	Life Sciences
Volume V	Communications/Navigation		



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INTRODUCTION

The ultimate goal of NASA's Materials Science and Manufacturing in Space (MS/MS) program is to institute commercial manufacturing and research activities in space, and thereby to secure a permanent future for manned space flight as a profitable contributor to the world economy. In the long run, it is expected and intended that such activities will come to be carried on primarily by private enterprise. During the 1970's and 1980's, however, the creation of capabilities and invention of space processes will depend on Government initiative, for private entrepreneurs will be unable to enter the field until it has been properly prepared.

TECHNICAL BASIS

The feature of space flight that the MS/MS program seeks to exploit is extended free-fall (often loosely termed zero gravity or weightlessness), which makes many novel manipulations of materials possible and alters the behavior of certain chemical and physical processes. For example, in free-fall it is possible in principle to melt and solidify arbitrarily large masses of material without physical contact, and to carry out a variety of contactless processing steps while the material is molten. Several potential applications of this type are portrayed in the experiment descriptions given in the following text, and it is expected that contactless processing and experimental research techniques will prove to be a very fertile field of invention as the program proceeds.

Convection and buoyancy are suppressed in fluids in free-fall, which should make it possible to produce controlled temperature distributions in liquids and gases, to control the positions of particles or voids in liquids, and to produce heterogeneous compositions that do not mix except by diffusion. These effects offer a new dimension of control for experiments on chemical and physical phenomena in fluids and a basis for many technical applications. Among the latter are the production of sophisticated composite materials, growth of large and highly perfect crystals from solutions and vapors, and methods for purifying materials such as chemicals or biological compounds by separation in fluid media.

Finally, there are many prospects for novel or refined scientific experiments in an environment where the dead weight of the sample or apparatus is not a disturbing factor. The nominal weightlessness experienced in free-fall may also make it possible to carry out highly refined machining operations, such as the ruling of diffraction gratings, to closer tolerances than are achievable on earth.

Thus, free-fall opens a wide field for new research and development activities in most areas of materials science and technology. Many interesting and promising

suggestions have already come to light, and there is reason to believe that more and better ideas will arise as our understanding of phenomena in weightless materials matures.

PROGRAM OBJECTIVES

The technical arguments outlined above make us confident that the MS/MS program's ultimate goal can be achieved. To lay the necessary groundwork for this achievement, the program will pursue the following broad and specific objectives in the 1970's and 1980's:

a. Broad Objectives:

1. Develop the technical basis required for commercial use of manned space facilities to produce economically viable products for consumption or use on the ground.

2. Provide indirect economic benefits by exploiting the unique advantages of space laboratory facilities to solve critical experimental problems in materials science and technology.

3. When appropriate, initiate manufacturing operations in space by private enterprise for commercial purposes and by agencies of the Government for public purposes.

b. Specific Objectives:

1. Develop apparatus and experimental techniques to enable productive materials research and development work to be performed in space.

2. Secure broad involvement by the international industrial and scientific community to identify and pursue promising development work and significant materials research experiments in space.

3. Conduct a diversified program of ground research and space experimentation during the 1970's to define specific prospects for manufacturing in space and to provide data for future material and process developments in space and on the ground.

4. In the early 1980's (i.e., during the early years of Space Station operations) develop a few initial processes to the point of commercial feasibility for manufacturing in space.

5. Establish suitable relationships between the Government and industry so that private enterprise can conduct space manufacturing operations and secure proper protection for its proprietary rights in processes and products.

6. When spacecraft capabilities and the status of space processing and research methods permit, establish permanent orbiting facilities that can be used by non-Government organizations for product manufacturing and materials research and development work.

SECTION 1

MATERIALS SCIENCE AND MANUFACTURING IN SPACE

1.1 GOALS AND OBJECTIVES

In the period covered by the present document (roughly the mid-1970's to the mid-1980's) the MS/MS program's space activities will concentrate mainly on exploratory research, although development of promising processes will also be pursued to the extent warranted by the resources of available flight systems. With a background of experimental technique and apparatus technology based on the program's Skylab experiments and continuing research and engineering development activities, we expect to carry out a space experiment program that includes every relevant area of materials science and technology.

The basic objective of the program's research in this period will be to secure scientific results that will expand our knowledge of physical and chemical processes in materials and provide a sound basis for new process inventions. Some of the latter will no doubt concern new or improve processes for use on the ground, but many are expected to be for processes that work to unique advantage in free fall. These will be developed toward commercial-scale production as the scale of space operations expands, in parallel with an aggressive continuing program of exploratory research. When it appears that one or more new processes can be practiced profitably in space, arrangements will be made for commercial exploitation or, where appropriate, for production under Government auspices.

1.2 PHYSICAL DESCRIPTION

1.2.1 GENERAL EQUIPMENT DESCRIPTION. Materials Science and Manufacturing payloads for missions in the post-Skylab period must provide very flexible and general capabilities for research and development work in the MS/MS program's chosen technical areas, because the MS/MS experiment program will be open-ended, evolving from exploratory research in its early phases to product development and pilot production in later years. The program will evolve considerably even during the exploratory research phase, since the findings of early experiments will affect the directions taken by the work that follows and new ideas or discoveries may lead the program into unforeseen paths at any time. Thus it will never be possible to prescribe the MS/MS experiment program in specific detail for more than about a year in advance of its performance.

The approach adopted by the MS/MS program in view of these characteristics of its experiment program is to plan payloads comprising assemblies of modular equipment items that can be used together in many different ways to perform the widest possible

variety of experiments. Ideally, it is hoped that the inventory of MS/MS payload equipment will have sufficiently general and flexible capabilities so that no experiment in the program's field will require any special apparatus beyond minor items of fixturing and instrumentation. Since most new experiments will not require extensive hardware developments for their implementation, the MS/MS experiment program should be able to respond quickly to new possibilities and keep control of experiment costs.

In addition, the above approach can provide a basis for payload planning to cover a wide variety of mission options. Given a list of equipment available to make up payloads and a set of descriptions showing how various experiments use equipment taken from the inventory, engineers performing vehicle and mission studies should be able to size MS/MS payloads to fit mission resources and arrive at reasonable approximations of the MS/MS experiment programs their missions can support. The equipment descriptions in the present section and the experiment descriptions in following sections have been laid out to be used in this way. Section 1.2.2 gives brief descriptions of 60 different items of equipment which have been identified to implement a program of representative experiments defined by the NASA Review Group for Materials Science and Manufacturing in Space. Section 1.3, the Experiment Requirements Summary, includes a matrix chart that tabulates specifications for the equipment, shows which items are used for which experiments, and summarizes performance requirements for the individual experiments. The experiments themselves are described in Section 1.4, Experiment Program.

It should be emphasized, however, that these data comprise only a first approximation to what would be needed for fully detailed mission studies. The information given below treats broad generic classes of experiments as units, since the resources available to prepare this document were not sufficient for more detailed analysis. Within each experiment class there are many possibilities for partial implementation using less than the total resources listed in Section 1.3. These possibilities are not treated in the present document, but it is hoped that some reasonable way will be found to include them in later revisions.

The equipment inventory is broken down into four general classes of apparatus:

a. Basic Units, which are large items with an average weight of the order of 100kg (220 lb) and an average volume of 1 m^3 (35 ft^3). These include seven large pieces of experimental apparatus and three systems that provide control functions and utilities.

b. Internal Units, which are smaller items of apparatus to be mounted in the large basic units to configure them for specific experiments. Most of the internal units have no unique location and can be used interchangeably in several basic units.

c. External Units, which perform functions similar to those defined for internal units, but which are to be mounted on the outside surfaces of basic units and therefore affect the outline dimensions of equipment configurations.

d. Support Units, which fall in the same size range as the basic units but are used for general supporting functions such as servicing and sample evaluation.

The functional relationships of the different types of equipment units are illustrated in Figure 1-1, and a schematic example of an equipment configuration including basic, internal, and external units is shown in Figure 1-2. The latter figure also illustrates the modification of the setup for different experiments by changing internal and/or external units.

1.2.2 DESCRIPTION OF INDIVIDUAL EQUIPMENT UNITS

1.2.2.1 Basic Units. The first four basic units are environmental chambers for the performance of all experiments of Classes 1, 2 and 3 as well as some experiments of Class 5. (Experiment classes are defined in Section 1.4.) They provide a wide range of functional capabilities; the major characteristics or differences of the four chambers are identified in qualitative terms in Table 1-1.

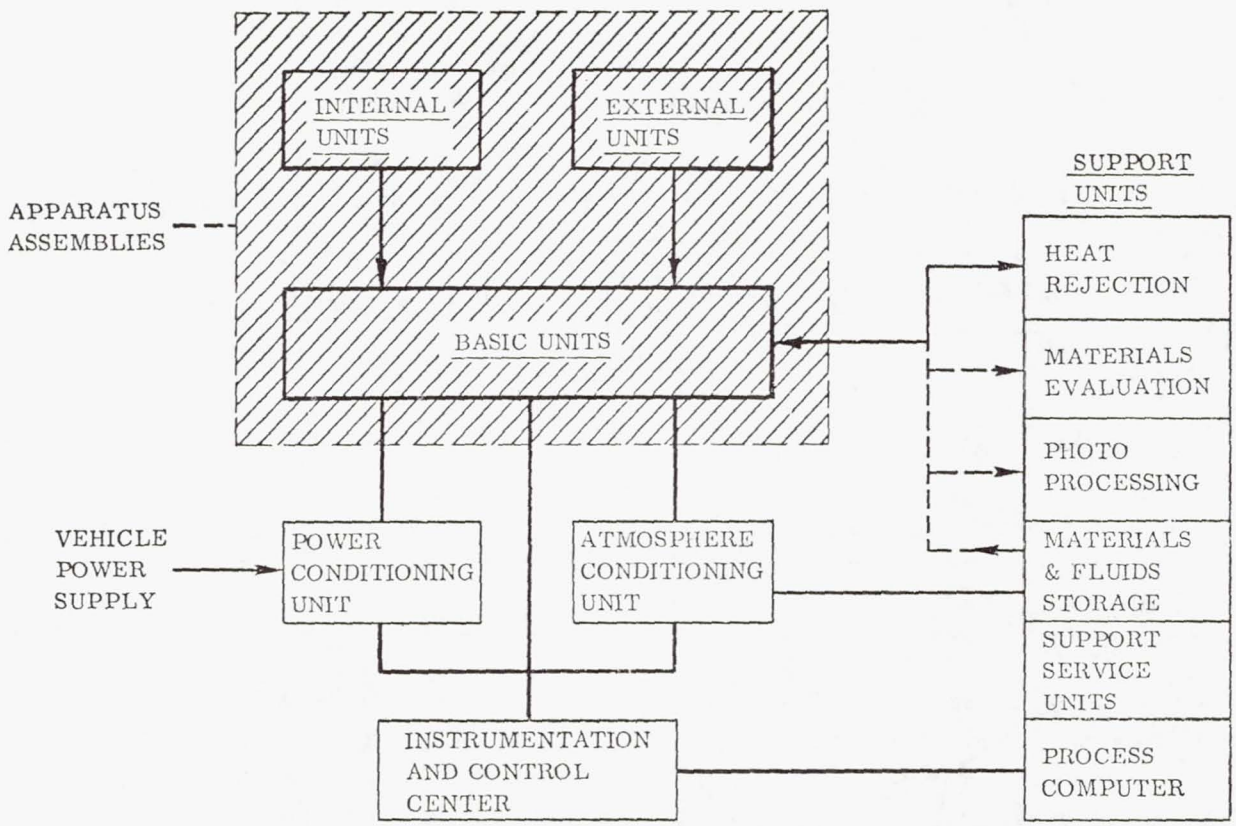


Figure 1-1. Functional Layout of MS/MS Equipment

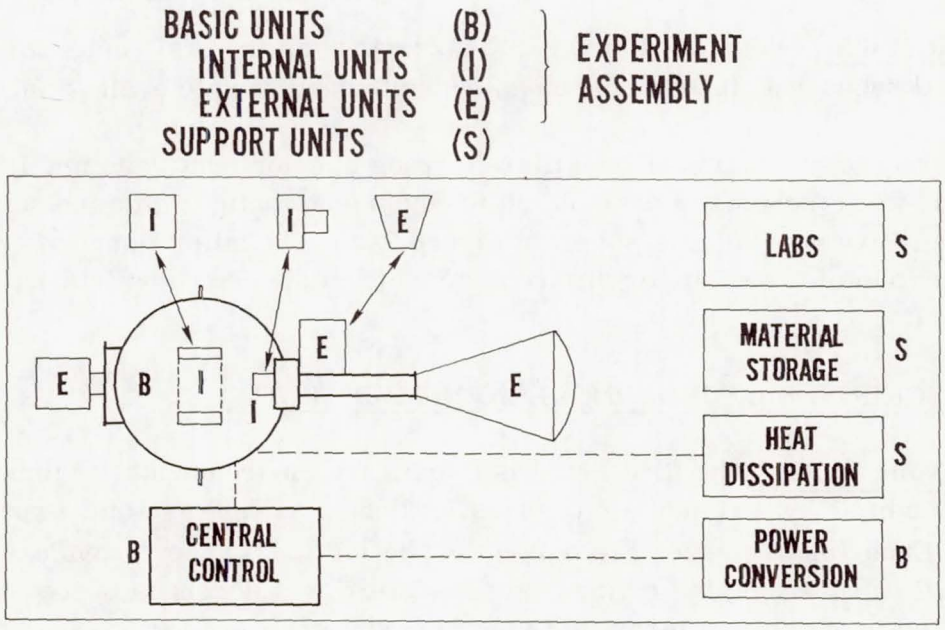


Figure 1-2. Equipment Units and Assemblies

Table 1-1. Major Characteristics of Environmental Chambers

Capability	B-01	B-02	B-03	B-04
Size	Large		Intermediate	
Atmosphere Control	High	Moderate		
Max. Temperature	(1800°K)	1800°K		2550°K
Cooling	Passive			Active

Chamber B-01 is primarily designed for experiments which require high-purity gas environment and highest vacua, including experiments at higher temperatures with a moderate rate of rejected heat. Chambers B-02 to B-04 are primarily designed for high-temperature experiments, with lesser emphasis on environmental control. Chambers B-02 and B-03 are identical in temperature capability and differ only in

size. Chamber B-04 is identical to B-03 in size, yet has a substantially higher temperature capability and active cooling.

The temperature maxima specified in Table 1-1 and the ensuing discussion of units have to be regarded as nominal, as the thermal conditions vary necessarily with the test material, the material mass and the time-temperature profile.

The four environmental chambers are similar in basic design concept. They employ a cylindrical chamber configuration, as it provides the optimum combination of the following requirements: 1) Accessibility for the installation of internal units; 2) structural simplicity, particularly for walls with cooling passages; 3) compatibility of port locations with thermal profile; 4) compatibility with cylindrical heating units; 5) accessibility for cleaning.

The basic design is illustrated in Figure 1-3. The stationary section consists of the vehicle attachment structure, one chamber end wall with accessories port for the installation of internal and some external units, and guide rails. The guide rails support the movable chamber section with main access port at its end wall and smaller view and instrumentation ports in the cylindrical section. For the installation of internal units, the movable section is disconnected from the stationary wall and moved to the end of the guide rails. In this position it can be turned $\pi/2$ rad (90 deg) around the Y-axis for cleaning and/or refurbishment. Functional characteristics are defined in the following individual descriptions.

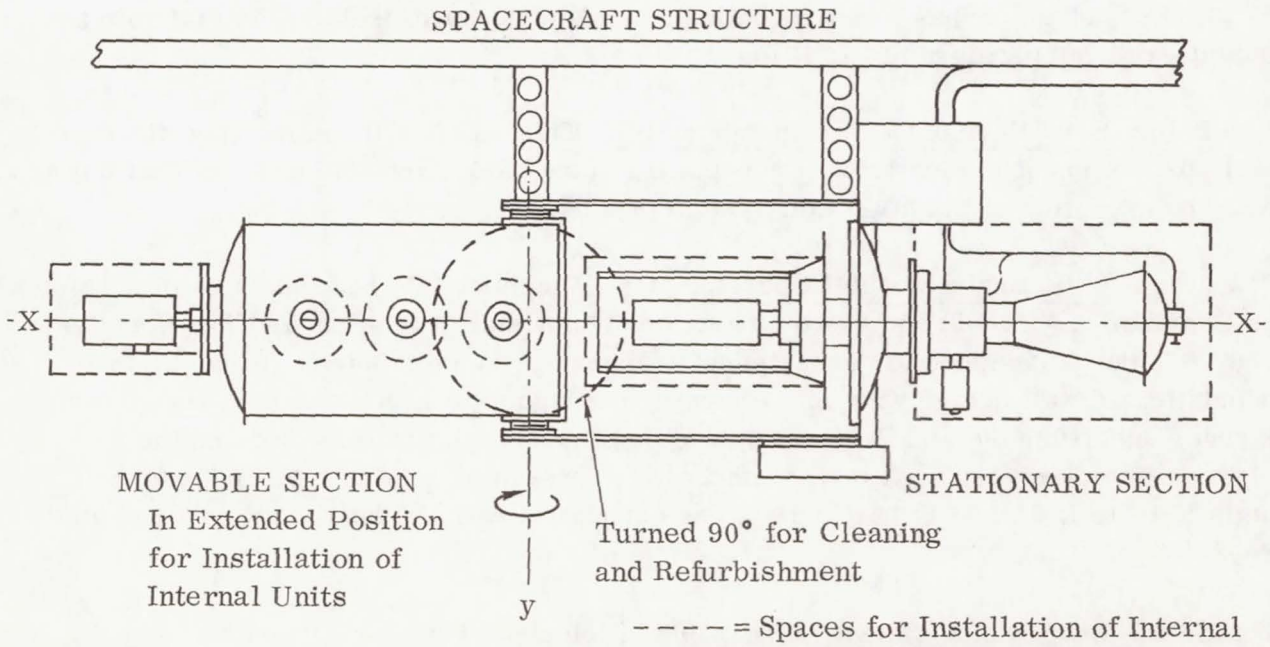


Figure 1-3. Basic Design of Environmental Chambers B-01, 2, 3 and 4

1.2.2.1.1 B-01 Controlled Atmosphere Chamber. The unit consists of a large, general purpose cylindrical enclosure with high vacuum or controlled atmosphere capabilities. The high purity atmosphere is provided by the atmosphere supply and control system (B-09). Wall outgassing is performed by positive ion bombardment. The unit has provisions for continuous atmosphere monitoring (E-01). Ion and sublimation pumps provide improved vacuum for those experiments requiring conditions better than ambient external pressure. The unit is capable of multifunction experiment utilization by incorporation of various internal apparatus and couplings with available external units. This includes experiments with levitated melts which require more precise atmosphere control than is obtainable in units B02, B03 and B04. It has, therefore, provisions for installation of such internal units as I-04, I-05, I-11 and I-12. Ready reconfiguration and refurbishment is a required design feature. Furthermore, safety and hazard control devices are included in the chamber structural design.

The unit length (x dimension) specified in Table 1-2 (folded in the envelope bound at the back of this volume) includes permanently installed external components such as pumps and control devices. Net chamber sizes are 0.8D x 1.4m (2.6D x 4.6 ft) (minimum capability) and 1.0D x 1.7m (3.3D x 5.6 ft) (desirable capability).

1.2.2.1.2 B-02 Environmental Chamber "A". This is a larger chamber for high temperature experiments to 1873°K (1600°C) max. The environment may be air, inert gases or vacuum to 10^{-6} mm Hg, all supplied from, and controlled by, unit B-09. Unit B-02 accepts furnace I-01 for mold-experiments, the actively cooled furnace unit I-03, and coils I-04 for contact-free heating and position control. For Class 1 experiments, it may be connected with unit B-06 for continuous liquid material supply. It is adapted further to internal units I-06 to I-15 and external units E-03 to E-12 and E-15. This chamber has passive cooling and adequate wall insulation to maintain an outside wall temperature of 315°K max.

1.2.2.1.3 B-03 Environmental Chamber "B". This unit has the same specifications as B-02, except it is smaller. It accepts the same basic, internal and external units with the exception of the large coil system of I-04.

1.2.2.1.4 B-04 Environmental Chamber "C". Chamber "C" has the same dimensions as Chamber "B" (B-03) and has the same environmental provisions as Chambers "A" and "B", but is designed for experiment temperatures up to 2550°K. It has a more sophisticated wall design with active cooling passages. It is primarily designed for furnace unit I-02, the smaller heating and positioning coils of set I-04, and the electron beam unit I-05. It further accepts internal units I-06 to I-16 and external units E-02 to E-12 and E-15. It requires connection with the heat rejection system S-02.

1.2.2.1.5 B-05 Biological Enclosure. The Biological Enclosure provides for isolation of biological processing activities, involving hazardous materials, from the shirtsleeve laboratory space and primary life support system. Because the materials

in question may be pathogenic or highly toxic, the enclosure provides self-contained gas circulation and emergency systems to control any accidental spill or release. The enclosure consists of two main interconnected units which are the work chamber and a self-contained gas recirculation unit. The experimental working chamber operates at a slightly reduced pressure from the laboratory ambient, and contains sealed gloves, a viewing port, and an isolated biochemical storage area. The chamber includes an internal accident control system consisting of germicidal UV lamps and a phenol or formaldehyde shower. If a leak or breakage occurs during operation, the system is activated either automatically or by the operator to disinfect the enclosure. The gas recirculation unit consists of an enclosed chamber which filters, heat-sterilizes, recirculates, and regulates the gas going through the experimental working chamber.

1.2.2.1.6 B-06 Liquid Metal Supply System. The function of this unit is to melt experimental metals and to feed the liquid material to mold-injection devices (I-06) or deployment systems for free casting (I-08, I-09). It is exclusively used for Class 1 experiments and attached to any of the environmental chambers B-02, B-03, and B-04. Even though it is an interchangeable external attachment to these units, the supply system is classified as a basic unit, since it acts as base assembly for various external units. It consists of a resistance-heated conical melting and supply chamber and a feeding system which has provisions for attachment of units E-07, E-08, E-10 and E-18. Feeding is accomplished by a gas pressurizing system, monitored by the mold or chamber pressure. It has a control accuracy of $10^{-5} \pm 1 \times 10^{-6}$ mm Hg, required for the deployment of liquid spheres into a vacuum environment.

1.2.2.1.7 B-07 General Purpose Laboratory Installation. This is a highly versatile unit for research experiments of Class 5, Physical Processes in Fluids, and for the support of other experiment classes. It is further used for the checkout of instruments or small equipment units, and for the study of experimental processes in simulation tests. The unit consists of a rack system which can be modified for the assembly of a variety of experiment arrangements and a table-top with hold-down capabilities. It has outlets for power, gases and vacuum and is connected with the Instrumentation and Control Center. The unit further includes a number of typical laboratory devices, such as small heating units, enclosed crucibles, and various measuring instruments.

1.2.2.1.8 B-08 Instrumentation and Control Center. All experiment performance functions are controlled by an Instrumentation and Control Center which can be connected with all basic experiment units, and some support units. It carries out the following functions:

a. Preprogrammed experiment performance control, in connection with the Process Control Computer, Unit S-01.

b. Automatic controls.

c. Display and recording of the outputs of sensing elements.

d. Interface between sensors and control systems.

e. Immediate data reduction and display via unit S-01.

f. Visual displays, including closed-circuit TV and TV recording.

g. Voice transmission and recording.

h. Manual override controls.

i. Activation of unit-integrated safety devices and/or the accident control system (S-08).

It consists of a main control and display unit, which serves as an observation post for the principal operator, and four modular units for 1) gas and pressure controls, 2) power controls, 3) measuring and electronic control circuits, and 4) recording center. Support unit S-01 (process control computer) may be integrated in the control center as a fifth module. The modular arrangement permits expansion of the unit, if necessary, by additional modules. The same concept applies to experiments in Shuttle-sortie missions, except in a scaled-down version.

1.2.2.1.9 B-09 Atmosphere Supply and Control System. The function of this unit is to condition and distribute gases to various points of use. In most cases this requires only an intermediate gas purity and pressure accuracy; for highest atmosphere control, as required for chamber B-01, this unit acts as a preconditioning system, while the devices for ultimate conditioning are incorporated in the working units. Gases are supplied from the Fluids Storage (S-06) partially by pipelines and partially by attachment of gas containers directly to the unit. Vacuum is supplied from the external environment by means of a large diameter duct. The unit incorporates solenoid valves, pressure reducers and controls, manifolds, gas mixing sub-units, and gas recirculation-purifying devices. The unit is exclusively controlled from the Instrumentation and Control Center (B-08). Manual operations are confined to the attachment of gas bottles and the opening or closing of main intake valves.

1.2.2.1.10 B-10 Power Conditioning and Distribution System. As illustrated schematically in Figure 1-1, this unit is an intermediary device between the vehicle main power supply and the various experiment units, controlled by the Instrumentation and Control Center. The unit consists of two sub-units, which may be at separate locations:

a. A power conditioning unit, which isolates the MS/MS payload from the spacecraft busses and performs any voltage and/or frequency conversions and regulation functions needed to convert from forms of power supplied by the spacecraft power system to special forms required by the experimental apparatus.

b. A storage battery system capable of supplying 15 kilowatt hours at a maximum discharge rate of 90 kilowatts.

The unit is monitored exclusively, including manual operations, by the Instrumentation and Control unit (B-08), and includes provisions for automatic emergency shutdown upon signal from the Instrumentation and Control unit.

The power ratings in parentheses in Table 1-2 represent battery power supplied directly to unit E-17 which, in turn, converts it into the high frequencies required for units I-03, I-05, I-11 and I-12. The weights include a reasonable amount for cables and wiring used to distribute power to the MS/MS payload.

1.2.2.2 Internal Units

1.2.2.2.1 I-01 Furnace, 1875°K (1600°C). This is a tube furnace-type heating unit with a maximum temperature capability of 1875°K (1600°C) in inert gas or vacuum and 1675°K (1400°C) in air, for use in chambers B-01 to B-04. The resistance heating elements are supported by a cylindrical thoria body, backed with metallic radiation shields to reduce heat transfer to the chamber walls. Supports and electrical leads are located at one end, leaving complete clearance for the object to be heated. Viewing access from the chamber view port can be provided at either end. The furnace operates without any active cooling.

1.2.2.2.2 I-02 Furnace, 2575°K (2300°C). This furnace represents the maximum temperature achievable by resistance heating; its temperature capability covers 95% of experiments with metallic materials. If higher temperatures are required, induction heating units I-04 are used for metals and unit I-03 for nonmetallic materials. The design of this furnace is similar to I-01, using tungsten heating elements and a more extensive radiation shielding system. It operates only in inert or reducing gas atmosphere or vacuum of 10^{-5} mm Hg. All leads and supports have provisions for active cooling, to be activated if necessary. The furnace is primarily used in the actively cooled chamber B-04, but can also be installed in units B-01 to B-03 for short-duration experiments.

1.2.2.2.3 I-03 Chamber-Furnace, 3475°K (3200°), Oxygen. This furnace represents a self-contained environmental chamber with integrated heating systems capable of temperatures to 3475°K (3200°C) maximum, and oxygen atmosphere. It is primarily designed for contact-free processing of small masses of oxides in an oxygen-rich atmosphere, but may also be operated with vacuum for free processing of small masses of refractory metals.

The unit consists of a sealed spherical inner chamber which contains a permanently installed and actively cooled coil system for heating and position control. The inner

chamber wall is constructed of thoria which can be heated to 2575°K (2300°C) by means of tungsten elements covering its outer surface. The outer chamber is of cylindrical configuration whose metallic walls are actively cooled.

For servicing, the inner and outer chambers can be opened; the exchange of samples, however, requires merely opening of the small view and access ports located at the side of the corresponding (larger) ports of the basic chamber in which the unit is installed. The space between the inner and outer chambers is vented to the basic chamber in which the unit is installed. The basic chamber is operated with inert gas or vacuum.

For experiments with oxides, the sequence of operations is as follows:

a. Generation of inert/vacuum environment in the basic chamber and oxygen environment in the inner chamber.

b. Activation of the position control function of the coil system.

c. Activation of the cooling system.

d. Heating of the inner chamber wall to 2575°K (2300°C).

e. Activation of the induction heating function of the coil system; heating of the samples to the desired processing temperature.

f. After predetermined processing time, either instantaneous or gradual deactivation of all heating systems, depending on sample cooling requirements.

g. Cutoff of inert gas/vacuum and oxygen supply, and venting of both chambers.

h. After cooling of the inner chamber to touch temperature, deactivation of cooling system and removal of sample.

For experiments with refractory metals, the same procedure is followed, with the exception of the use of inert gas or vacuum in the inner chamber instead of oxygen. While metal samples could be heated by induction only, the heating of the inner chamber wall to an appropriate temperature enhances the thermal effectiveness of the inner chamber.

1.2.2.2.4 I-04 Heating and Positioning Coils. This unit consists of several sets of coil systems for electromagnetic position control and induction heating. In general, each experiment requiring levitation control and/or induction heating will require specially designed coils to meet its particular coupling requirements. All coils have provisions for active cooling, to be used wherever necessary. VHF power is supplied to all coils from unit E-17, which, in turn, receives power from B-10; for higher input requirements, the power supply is supplemented from storage batteries of unit B-10. All coil systems are adapted to installation in Environmental Chambers B-01 to B-04. Smaller coils (1 and 2, above) may also be installed in unit B-07 for research and checkout experiments.

1.2.2.2.5 I-05 Plasma Electron Beam Unit. This unit consists of a plasma generator and a means for focusing an electron beam to the surface to be heated. The unit is used for heating dielectrics (oxides) to extreme temperatures and for fire-polishing glass bodies. The unit is attached to Environmental Chambers B-02, 03 and 04, and obtains power from the Power Conditioning System (B-10). It is used for performing Class 3 (Glass Processes) experiments involving high-temperature dielectric materials melting, and selected Class 2c experiments with metallic materials.

1.2.2.2.6 I-06 Mold-Injection System. This is a pressure-controlled device for the injection of liquid metals supplied from unit B-06 into molds. The unit is adapted for installation in basic chambers B-02 to B-04 and accepts all molds of set I-22.

1.2.2.2.7 I-07 Dispersion Control System. The purpose of this unit is to generate either a uniform or a controlled-variable dispersion in composites and foams after their injection into the mold. It consists of a set of transducers of various shapes which can be assembled on a cylindrical support grid in various arrangements to produce the desired control function. The unit is exclusively used in connection with molds of set I-22 and is attached to the accessories bulkheads of units B-02 to B-04. It receives HF power from unit E-17, with programmable frequencies and inputs. The unit is used primarily in experiment Classes 1A, 1B and 1D.

1.2.2.2.8 I-08 Liquid Sphere Deployment System. This is an orifice assembly with a mechanical actuating system which deploys liquid spheres into a position control system. It receives liquid material from unit B-06. The term "deployment" comprises two functions: 1) growing of the sphere at an orifice to a finite size and 2) detachment from the orifice and contact-free injection in the position control system. The growing of the sphere is controlled by the feeding system of unit B-06 and monitored by pressure sensors installed in the orifice section. The unit has a mechanical detachment system whose forward and retraction motions are accurately controlled to produce either zero motion of the detached sphere or a slow motion toward the position control system. The unit is designed exclusively for Class 1C experiments.

1.2.2.2.9 I-09 Hollow Bodies Deployment System. This unit is similar in size and design to unit I-08, except that the orifice section consists of two coaxial nozzles: 1) a larger outer nozzle for the growing of the initial liquid sphere and 2) a small nozzle for the injection of gas into the liquid sphere. The inner nozzle can be held in fixed position or can perform a controlled backward motion commensurate with the growth of the bubble. The unit includes a pressure control system for the injected gas which is monitored by the pressures in the chamber and in the liquid material supply system.

1.2.2.2.10 I-10 Membrane Drawing Tool. This is a mechanical device for contact-free (except for contact at edge members) drawing of metallic or nonmetallic membranes. It consists of a rectangular frame system, enclosed in an integrally heated rectangular box with open ends, and a sealed mechanical actuator. The frame system

has two stationary and two movable edge members which contain the material supply. After achieving operating temperature, the membrane is drawn by edge movement from touch position. Membrane formation and thickness are controlled by the pre-arranged adhesion characteristics between the liquid material and the deployment edges. Experiments require controlled environments and are carried out in chambers B-01, B-02 or B-03.

1.2.2.2.11 I-11 Zone Melter. The unit is utilized for floating-zone melting and solidification studies. It consists of a programmable speed control for either induction or electron-beam zone melting, and a capability of controlling the shape of the molten zone. The bar to be float-zone melted may either be supported at the ends or held in place by a position control system. This unit is utilized with Environmental Chambers B-01 or B-03, and power is provided by the VHF power unit (E-17) and/or the Power Conditioning System (B-10) in performing Class 2 experiments with metal samples.

1.2.2.2.12 I-12 Czochralski Crystal Puller. The Czochralski method produces single crystals by partially inserting a single crystal seed into a melt of the same material and withdrawing the growing single crystal at a programmed rate. This device consists of a programmable position/removal rate seed-crystal holder, coupled with a position control system for holding the levitated melt in place while the crystal is being formed and pulled. The unit is utilized with Environmental Chambers B-01 or B-03, and power is provided by the VHF Power Unit E-17. The unit is used in performing Class 2 single-crystal experiments with either metals or compounds.

1.2.2.2.13 I-13 Susceptor for Silicate Melts. This unit consists of a cylindrical platinum susceptor coupled to an induction coil in order to permit containerless melting of poorly conducting silicate salts for crystal growth. The device is utilized with Environmental Chamber B-03 and power is provided by the Power Conditioning System (B-10).

1.2.2.2.14 I-14 High-Temperature Calorimeter. The unit consists of a modified differential thermal analyzer, consisting of a furnace with two isolated isothermal cavities. Each cavity is independently temperature controlled with a power monitor. The reference cavity contains a sample with a known heat capacity equal to the heat capacity of the experimental sample in the other cavity at the measurement temperature. During the experiment, the temperature of both cavities is raised or lowered simultaneously, and the power input in either of the cavities for maintaining isothermal conditions in both cavities is monitored. The integrated difference between the power required to maintain the two cavities at the same temperature indicates the amount of energy gained or lost by the experimental sample at the transition temperature. This unit is utilized in the Controlled Atmosphere Chamber (B-01) and is used in Experiment Class 2D.

1.2.2.2.15 I-15 Seed Injector. This device consists of a magnetically controlled seed injector rod. It is used to insert single crystal seeds, attached to the rod, into melts in closed containers, or into levitated melts at solution saturation to produce a single crystal. The external magnets, coupled to the seed-injection rod magnet, are programmable for position and insertion/removal rate control. The seed injector is used in Environmental Chamber B-03. Its application is for Class 2 single-crystal experiments.

1.2.2.2.16 I-16 Internal Friction Measuring Device. This unit consists of a position sensing system with controlled feedback to oscillate a molten mass throughout a frequency range in order to determine the resonant frequencies of the mass and establish the amount of power necessary to maintain the oscillatory motion. The temperature of the molten material will be monitored during the internal friction measurements. This device will be used with Environmental Chamber B-01, primarily for Class 2 nucleation studies.

1.2.2.2.17 I-17 Stationary Electrophoretic Column Assembly. This unit is composed of ten stationary electrophoretic columns, each capable of being operated independently if desired. Each column consists of a cylindrical cooled tube with electrode compartments at each end, separated from the main column by semipermeable membranes, and is provided with liquid circulating systems to remove gas evolved at the electrodes and to cool the column (I-20). The sample injection and fraction removal ports are located at the ends of the main column. Buffer recovery and waste disposal will be performed using the Buffer Recovery/Waste Disposal System (I-19). The columns are mounted so that a UV microdensitometer (E-13) or a Holographic Interferometer (E-14) can be utilized to monitor the progress of the experimental runs. Two units will be utilized, one inside the Biological Enclosure (B-05) for toxic materials, and one with the General Purpose Laboratory Installation (B-07) for research work on innocuous samples. Power for the columns will be supplied by the Power Conditioning System (B-10) and the experiments will be automatically controlled by the Process Control Computer (S-01) except for routine monitoring by the experimenters. These units are used for the Class 4 Biological Processing Studies.

1.2.2.2.18 I-18 Continuous Electrophoretic Column Assembly. This unit is composed of multiple continuous electrophoretic columns, each capable of being operated independently if desired. Each column consists of a cooled, thin, rectangular chamber with electrode compartments running along two sides. Several sample injection ports are located at the end nearest the buffer injection edge, and many fraction collection ports are located at the end nearest the buffer removal edge. Buffer injection and removal edges are perpendicular to the edges containing the electrodes. The Buffer Recovery/Waste Disposal System (I-19) will be used to recycle used buffer and remove the unwanted materials. The gas generated at the electrodes will be removed and the unit cooled by the Gas Elimination/Cooling System (I-20). The columns will be mounted such that each column can be examined by a UV microdensitometer (E-13) or

a Holographic Interferometer (E-14) for monitoring the progress of the experiment. Two units will be utilized, one inside the Biological Enclosure (B-05) for toxic materials, and one with the General Purpose Laboratory Installation (B-07) for research work on innocuous samples. Power for the columns will be supplied by the Power Conditioning System (B-10) and the experiments will be automatically controlled by the Process Control Computer (S-01) except for routine monitoring. This equipment will be used for performing Class 4 Biological Processing Studies.

1.2.2.2.19 I-19 Buffer Recovery/Waste Disposal System. This system receives the waste buffer solution from both the stationary and continuous electrophoretic installations (I-17 and I-18), filters the solution through ultra filters and recovers the water by reverse osmosis. After the water has been recovered, the apparatus is sterilized by passing a phenol or formaldehyde solution through the system in the Biological Enclosure (B-05), and the used filters and biological wastes are carburized. A separate Buffer Recovery/Waste Disposal System may be utilized with the General Purpose Laboratory Installation (B-07). The system could be cleaned in the ultrasonic cleaner located with the installation. The equipment is used to perform the Class 4 Biological Processing Studies.

1.2.2.2.20 I-20 Gas Elimination/Cooling System. This system is used in conjunction with the Stationary Electrophoretic Column Installation (I-17) and the Continuous Electrophoretic Column Installation (I-18). The system removes gases produced during electrophoresis from the buffer solution in the electrode compartment by a surface tension screen and phase separator. The degassed buffer solution is cooled by a heat exchanger; the cooled solution is then recirculated through the cooling chambers of the electrophoretic columns and the electrode compartments, or returned to storage for reuse. Recirculation of the cooled buffer solution is to bring the solution in the electrode compartments and the separation columns to the same temperature. Two systems are utilized: one is located in the Biological Enclosure (B-05), and another with the General Purpose Laboratory Installation (B-07). This equipment is used to perform Class 4 Biological Processing Studies.

1.2.2.2.21 I-21 Lyophilization Apparatus. The apparatus contains a rack of 100 vials. Each vial is capped with a septum which is part rubber to accept collected fraction injection needles and part semipermeable membrane to allow subsequent passage of water vapor. After the vials are filled, the rack is cooled to 273°K (0°C) to freeze the liquid samples. When the fractionated material/buffer solution is frozen, a top is clamped on the rack and vacuum is applied. After the unbound water is removed by sublimation, the rack is heated briefly (303°K) to remove the bound water. The vials are then sealed under vacuum and the system repressurized. This apparatus is located in the Biological Enclosure (B-05), since the sealed vials will be stored in the storage cabinet maintained in the enclosure. This equipment is used to perform Class 4 Biological Processing Studies.

1.2.2.2.22 I-22 Molds, Cavities, and Crucibles. This unit represents a set of selected metallic and oxide or oxide-coated molds and cavities for Class 1A, 1B and 1D experiments, and several glass containers and crucibles for Class 5 experiments. The open-end flanges are of standardized design for convenient attachment to the Mold Injection System (I-06) or to unit B-07.

1.2.2.2.23 I-23 Minor Internal Attachments. This set consists of a variety of minor structural components, such as adaptors, brackets, clamps or seals which are not included in the structural units but may be required for equipment modification or refurbishment. All components are made of heat-resistant materials.

1.2.2.3 External Units

1.2.2.3.1 E-01 Continuous Atmosphere Analysis Apparatus. This apparatus consists of a combined gas chromatograph and mass spectrometer unit which is capable of detecting and analyzing impurities in the ppm-ppb range. It is used principally with B-01 to perform studies requiring careful atmospheric characterizations. This apparatus will be used in the preparation of high-purity metals, crystals, and glasses of Classes 1, 2 and 3.

1.2.2.3.2 E-02 High-Temperature Viewing Device. This device is a laser microscope, capable of taking holograms of materials at very high temperatures. The device uses a pulsed ruby laser to view and photographically obtain a hologram of the material at temperature. Due to the effective brightness temperature of the pulsed light, the incandescence of the material does not impair the quality of the hologram. The hologram contains detailed surface information of the object and allows microscopic examination of the hologram to provide information regarding the behavior of materials at high temperatures. The unit is applicable to viewing high-temperature interfaces and processes for Classes 1, 2 and 3.

1.2.2.3.3 E-03 Chill System. This system is a movable coolant reservoir with a recirculation pump to be used 1) for connection with coolant passages for accelerated cooling rate of experiment materials where the high cooling capability of the heat rejection system is not required, and 2) for accelerated cooling in case of a potential hazard. It can also produce a free coolant jet whose use is, however, highly undesirable and confined to cases of critical emergency. It includes a flexible cooling blanket with coolant passages.

1.2.2.3.4 E-04 Motion Picture Camera. This is an electrically operated camera for magazine loading with 120 m of 16 mm film (11 min at standard speed). It has interchangeable lenses for object-lens distances from 0.1 to 2 m. Its specification includes adapters to experiment units. Specifications call for several cameras to permit installation for extended time.

1.2.2.3.5 E-05 TV Camera. This is a standard high-resolution (10^7 bps) TV camera as used in space and aircraft applications. The camera head and control unit integrated in one unit. Specifications include weight and volume for coaxial cable to recording or transmission station and for adapter kits. Several cameras are provided to permit concurrent installation for extended periods.

1.2.2.3.6 E-06 Remote Measuring (Mass, Dimensions). The remote and contact-free measuring of the dimensions of hot bodies is accomplished exclusively by holographic methods. A hologram contains both amplitude and phase information, while a conventional photograph contains only the amplitude information. The phase information stored in the hologram is recorded by combining a scene wavefront with a reference wavefront from a laser to produce an interference pattern having a very fine spacing. When the holographic plate is reilluminated for viewing with the reference wavefront only, the scene wavefront is reconstructed by diffraction from the interference pattern. The scene wavefront reconstruction allows an investigator at any time to make all the optical observations and measurements on the holographic image as if it were the original object. Thus the use of holographic techniques allows convenient measurements to be performed on remote objects that cannot be physically touched.

1.2.2.3.7 E-07 Mixing Unit - Liquid/Solid, Liquid/Liquid. This unit is a device for 1) dispensing of solid particles or a second liquid phase into a liquid to form a base-mixture for composites or liquid dispersions, and 2) mixing or homogenization with a controllable degree of dispersion. It consists of a mixing chamber and interchangeable conical dispersion-material supply chambers, all with resistance-heated and insulated walls. Permanently attached to the chamber wall are two agitators: 1) a mechanical vibrator similar to, but smaller than, unit E-10 for mixing and 2) several ultrasonic transducers for homogenization. For coarse composites, only the first unit is used. For homogenization both units are used sequentially. The high frequency power for the transducers is supplied from unit E-17. The unit is primarily used as an attachment to the feeding section of the Liquid Metal Supply System (B-06). However, for simple experiments with small masses, the unit may be attached directly to the outside of the Mold Injection System (I-06). In this case, the matrix metal is melted in the mixing chamber prior to the dispensing of dispersion materials.

1.2.2.3.8 E-08 Mixing Unit Liquid/Gas. The prime function of this unit is the production of metallic or composite foams. It is installed, as part of the liquid metal passage, between the Liquid Supply System (B-06) and the Mold Injection System (I-06). It consists of a small body with flanges at both sides in the x-direction for installation, removable plugs at both sides in the z-direction for the installation of various mixing nozzle assemblies in the liquid passageway, and a pressure control valve in the y-direction, which can either be connected with the Atmosphere Control and Supply System (B-09), or with a small tubular gas bottle. A number of interchangeable mixing valve inserts for various degrees of dispersion are included in this unit. For single experiments with small material masses, the material supply

system may be replaced by a small resistance-heated conical container with a manually adjustable needle valve which is also part of the unit, and the same provisions for gas supply as described above.

1.2.2.3.9 E-09 Slip-Cast Injection System. The injection unit for slip casting consists of two main components: 1) the injection head with a manual flow control valve and standard flanges for the attachment of the mold at one side, and the supply container at the other side in the x-direction; 2) a conical mixing and supply container with a permanently attached ultrasonic transducer for mixing and homogenization. The supply container can be opened for charging. Injection of the mix into the mold is accomplished by gas pressurization of the supply container from its large-diameter end. All casting operations are carried out in the General Purpose Installation (B-07). Special molds with provisions for closing of the injection inlet are included in set E-18.

1.2.2.3.10 E-10 Vibrators. This unit consists of three multipurpose vibrators and mounting hardware for temporary attachment at the point of use. The three vibrators are a small mechanical low-frequency shaker, a large mechanical variable-low-frequency shaker and an ultrasonic transducer which is powered by the low-power outlet of VHF unit E-17. All devices have a standard flange for attachment to various basic and external units. Otherwise, they can be temporarily attached with auxiliary hardware. The purpose of this unit is to induce liquid material agitation wherever and whenever need for such capability arises. The unit may be particularly useful in research experiments in the General Purpose Laboratory Installation (B-07).

1.2.2.3.11 E-11 Microscope Stage Attachment. This device consists of a small cell provided with viewports and programmable heating and cooling devices for microscopically observing and photographing solidification fronts in low-melting transparent materials. It is to be utilized with either a microscope in the Materials Analysis Equipment (S-04) or with a microscope provided with the General Purpose Laboratory Installation (B-07). The unit is used in Experiment Class 2.

1.2.2.3.12 E-12 Photometric Densitometer. This unit consists of a monochromatic light source and photocells to monitor film thickness as a function of photocell current. It is used in Experiment Class 2 and for the evaluation of membranes (Class 1C). Even though designated as an external unit, part of the instrumentation reaches into the internal section of the aparatus.

1.2.2.3.13 E-13 UV Densitometer. This device is used to measure the variation in ultraviolet adsorption in solutions being electrophoretically separated. The device is used in conjunction with the Stationary Electrophoretic Column Installation (I-17) and the Continuous Electrophoretic Column Installation (I-18) to obtain information on the separation speed and efficiency during the fractionation of biological materials. This device is used for Experiment Class 4.

1.2.2.4.2 S-02 Heat Rejection System. Many experiments in the MS/MS program will involve concentrated heat sources at high temperatures, and some will entail rapid discharge of heat from apparatus of high thermal capacity or dissipation of battery power in excess of the output of the spacecraft power system. The maximum heat load anticipated is of the order of 10.4 MJ (2500 kcal)/hr for periods up to two hours.

Special provisions will be required to dissipate these abnormal heat loads. The available options appear to be:

a. Direct connection of the MS/MS payload apparatus with the spacecraft thermal control system, with heat sinks and regulating devices to control the load imposed on the main radiators.

b. Provision of a special radiator system to serve the MS/MS payload. Since the optimum choice or compromise will depend on the nature of the vehicle system carrying the payload, definition of the exact method of heat rejection is left to the decision of users of this document. The weights and volumes listed for the Heat Rejection System in Table 1-2 represent an estimated average between the requirements for the above two options and should be re-estimated for the specific systems chosen in particular cases.

1.2.2.4.3 S-03 Cleanup and Refurbishment Equipment. This is a set of portable tools utilized to remove solid deposits such as vaporized metal films on equipment surfaces and to refurbish chamber liners and coatings for molds, cavities, etc. A supply of spare liners is maintained in the materials storage (S-06).

1.2.2.4.4 S-04 Materials Analysis Equipment. This installation consists of equipment for both metallographic and chemical analysis, plus ancillary supplies. It provides the necessary onboard capabilities for the evaluation of metals, single crystals, glasses, buffer makeup, composites or foams. More advanced analyses such as dislocation densities of single crystals, impurity concentrations, and electro-optical evaluation of optically active crystals will not be included. The equipment consists of a metallograph, sample preparation devices such as cutoff saws, polishers, an X-ray diffraction unit, a pH meter, volumetric displacement apparatus, and a zero-g balance. Miscellaneous chemicals for sample etchant and buffer makeup will be available. This capability supports onboard characterization of experimental materials and process solutions.

1.2.2.4.5 S-05 Photographic Processing Laboratory. Unless provided in the vehicle for general use by all disciplines, minimum processing equipment will be required for the processing of motion picture films and sheet film, and for the preparation of prints. This unit includes automatic processing tanks, film dryer, printer, and an editor-type motion picture viewing device.

1.2.2.4.6 S-06 Open Materials and Fluids Storage. This unit provides a general-purpose storage installation for experiment materials, fluids and products, and for general storage of equipment components, such as smaller internal and external units not in use, refurbishment components and materials, etc. Most experiment materials are packaged in small denominations. Fluids are stored in containers of variable size. Isotopes are stored in individually shielded containers.

1.2.2.4.7 S-07 Controlled-Atmosphere Materials and Fluids Storage. This unit consists of two enclosures: 1) An enclosure with a temperature-controlled inert gas environment for the storage of innocuous materials, fluids, and products which are temperature and atmosphere sensitive; 2) an isolated temperature- and atmosphere-controlled enclosure for the storage of toxic materials. Both enclosures have special access and material exchange provisions.

1.2.2.4.8 S-08 Accident Control System. This equipment supplements the hazard prevention provisions already integrated in individual equipment units for increased safety and for critical emergencies. It has the objective of protecting the crew, the spacecraft, the spacecraft environment, and the experiment equipment. It consists of a variety of manually operated tools and materials, such as fire extinguishers, tools for the removal of hot liquids, chemicals for the neutralization of spilled toxic liquids, or endothermic powders. They are designed for the control of high temperature liquids which may escape the experiment control and may not be fully restrained by the chamber safety provisions, even though such a situation is very unlikely. The equipment further includes heat-protective gloves, face masks, and body covers for the accident-fighting crew.

While the instrumentation control center has several redundant provisions for automatic power and pressurization cutoff in case of a potential hazard, a manual override is installed at the location of this equipment, as well as the Control Center, for the deactivation of all equipment except the cooling devices. An alarm system is activated in every case of a potential hazard, upon which the crew stays in readiness for the use of this equipment.

1.2.3 EQUIPMENT LAYOUTS. Typical layouts of several major equipment units in a space station module are illustrated in Figures 1-4 and 1-5. The majority of experiments are carried out in one of the basic environmental chambers (units B-01 to B-04), shown at the left in Figure 1-4. The biological enclosure with air

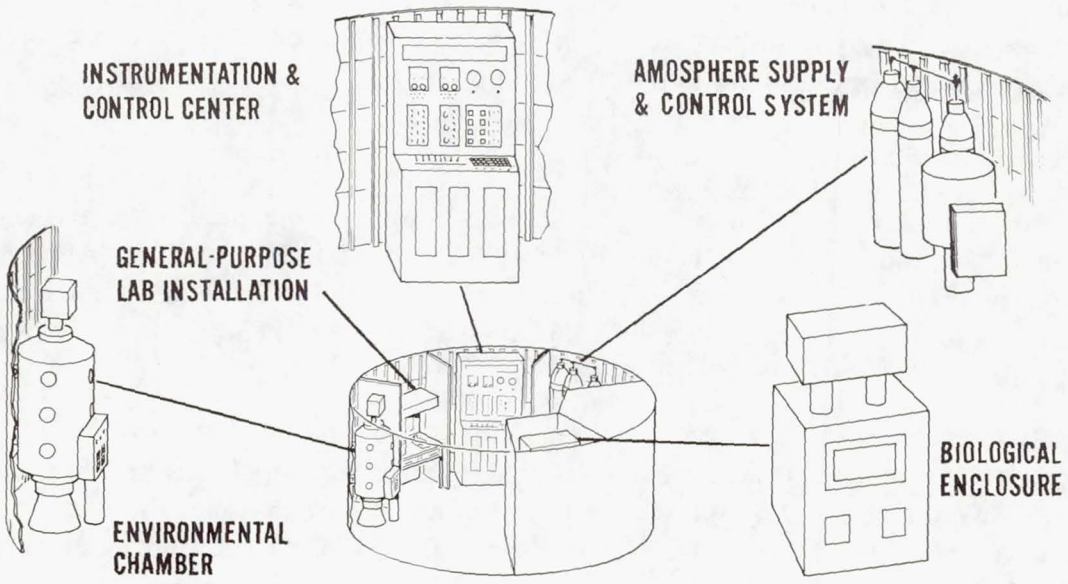


Figure 1-4. Typical MS/MS Equipment Layout

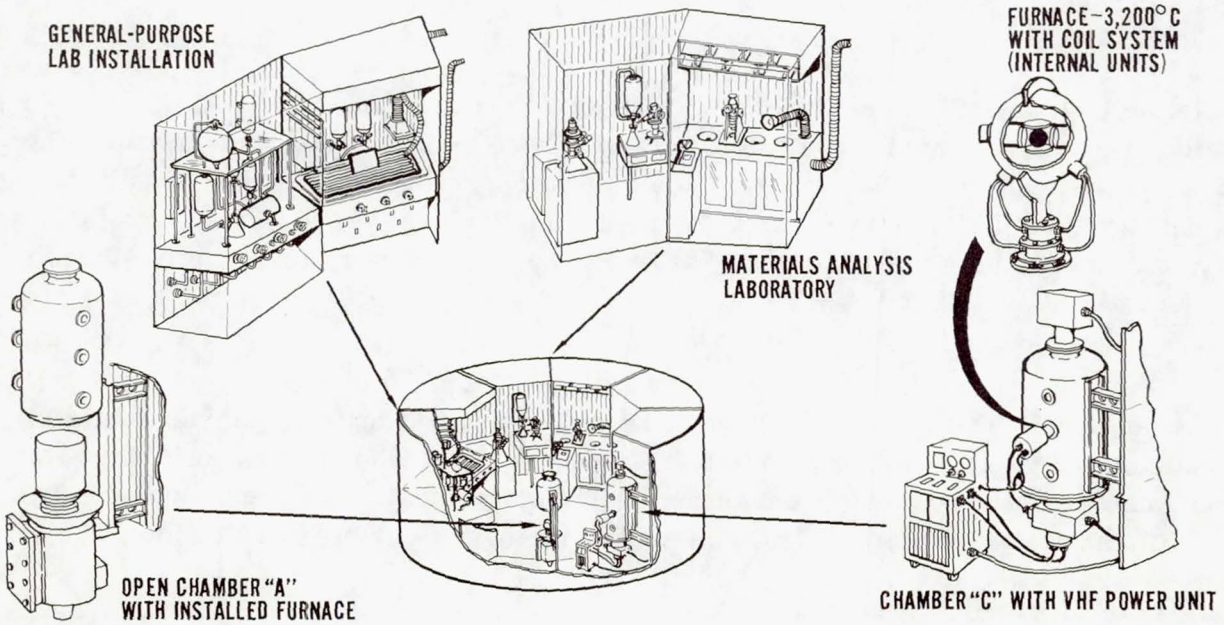


Figure 1-5. Typical MS/MS Equipment Layout

recirculation system (unit B-05) is shown at the right. All experiments are controlled from the instrumentation and control center (B-08).

Two other modifications of the basic environmental chamber are illustrated in Figure 1-5. The chamber at left is in open position for installation of a furnace unit (I-01, I-02). The chamber at right is in operational condition for a free-casting experiment; the VHF power unit (E-17) feeds the heating and positioning coil systems (I-04) shown in the close-up of the spherical chamber-furnace (I-03) above the apparatus. Two typical laboratory installations are illustrated at the top of Figure 1-5.

The functional and operational arrangement of major units, typical of all MS/MS experiments, is illustrated in Figure 1-6.

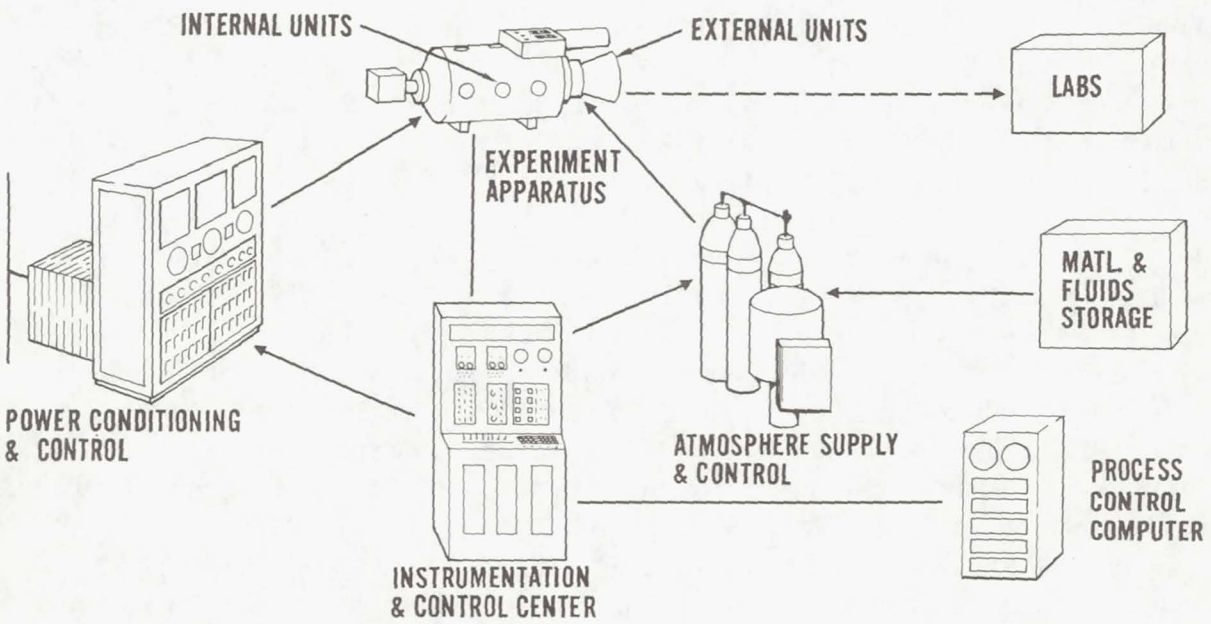


Figure 1-6. Functional Equipment Arrangement

1.3 EXPERIMENT REQUIREMENTS SUMMARY

Data on the equipment described in Section 1.2 and the requirements of the experiment program defined in Section 1.4 are compiled in Table 1-2, which is contained in the envelope bound at the back of this volume. Since this table contains all numerical data on the performance requirements for the experiments, the data are not repeated separately in the experiment descriptions given in Section 1.4.

Table 1-2 is divided into seven major blocks, which are numbered along the horizontal axis of the table and lettered along the vertical axis for convenience of reference. Blocks A1, A2, and A3 refer to the usage and specifications of the equipment described in Section 1.2. Blocks B1 and B2 identify crew skill requirements for the experiment program. Blocks C1 and C2 contain data on the resources needed to perform the experiments.

Block A1 of Table 1-2 comprises a list of the equipment in the payload inventory by number and name. Block A2 is a "commonality matrix" containing columns corresponding to all of the 13 types of experiments identified in Section 1.4. Equipment items used in performing a given experiment are indicated by circles in the appropriate column; a filled-in circle indicates a piece of equipment required for all experiments of a given type, and an open circle indicates an item used only for certain variations of the experiment. It will be noted that the major equipment items are used in common by most of the experiments.

Block A3 in the table contains the estimated dimensions, weights, volumes, power requirements, and data rates for the listed equipment items. These specifications are necessarily only approximate, since a detailed design study of any equipment item would show that the design parameters could be varied over rather wide ranges in response to constraints arising from costs, schedules, vehicle capabilities, etc. In lieu of parametric data, which are not yet available, we have listed two sets of design parameters: one representing approximate requirements for a minimum capability, and a second showing what would be desirable if the design were unconstrained. However, it should be observed that even these estimates are based on an implicit assumption that the vehicle in question has relatively large resources for payload support. The question of payloads for vehicles with limited resources has not been addressed, and estimates for such cases would require a new study.

Block B1 of Table 1-2 lists crew skills from the standard list developed for this handbook, and Block B2 indicates which skills are needed for each type of experiment. The filled-in circles indicate basic skills that are considered mandatory on the assumption that the crew functions essentially as a group of laboratory technicians following the instructions of experimenters on the ground. Additional skills that would be desirable if crew resources permit are identified by open circles.

Block C1 lists performance requirements for the experiments, such as acceleration levels, numbers of runs, time, logistic requirements, etc. Block C2 gives numerical data on these items for all of the experiments. Since the equipment can be assembled in many different ways and many items of equipment are common to several experiments, it was not considered meaningful to list total weights and volumes for individual experiments. In addition, the power levels listed for the experiments are only intended to be representative. Total weights, volumes, installed power requirements, and digital data rates for individual payloads taken from the equipment inventory should be compiled from Block A3 of the table in each case.

All data of Block C-2 represent the requirements of the experiment only. Power data entries, for example, do not include, and are those requirements in excess of, the 2-kW continuous consumption level of the MS/MS facility that is required for various support operations and for battery charging; power figures in parentheses indicate battery-supplemented power.

Total interface, support, and performance requirements for the Materials Science and Manufacturing in Space FPE are discussed in Section 1.5.

1.4 EXPERIMENT PROGRAM

The program presented in this section includes only those experiments for which the NASA Review Group for Materials Science and Manufacturing in Space could give reasonably detailed descriptions as of August 1970. In view of the program's newness at that time, some areas necessarily received incomplete coverage and some, such as chemical processes, had to be omitted entirely. The experimental areas covered in the descriptions have been classified and numbered as follows:

1. Metallurgical Processes
 - 1A. Composite Materials
 - 1B. Metal Foams and Controlled-Density Materials
 - 1C. Free Casting
 - 1D. Liquid Dispersions
2. Crystal Growth
 - 2A. Crystal Growth from Solution
 - 2B. Single Crystal Growth from Melts
 - 2C. Crystal Growth from Vapor
 - 2D. Supercooling and Homogeneous Nucleation
3. Glass Processes
 - 3A. Preparation of Glasses
 - 3B. Glass Processing

4. Biological Processing

 4A. Electrophoretic Separation
 4B. Lyophilization

5. Physical Processes in Fluids

 5A. Convection

This scheme is intended to permit the addition of new experiment descriptions to later editions of this document as the MS/MS program matures.

1.4.1 METALLURGICAL PROCESSES

1.4.1.1 Composite Materials

1.4.1.1.1 Scientific and Technical Objectives. Through experiments performed in free-fall, determine how basic solidification mechanisms act to determine the characteristics of metal-matrix composite materials, including cemented compacts, controlled eutectic structures, monotectic alloy structures, and metals strengthened by dispersions of fibers or particles.

Evaluate fundamental relationships between components of heterogeneous melts from which composite materials can be formed, such as surface energies, mixtures stability, wetting characteristics, dispersion and agglomeration, and nucleation of the melt by solid particles dispersed in it.

Develop methods and apparatus for producing unique or highly improved metal-matrix composites, with advantages such as very uniform or controllable structures, high densities of fibers or particles, and unique electrical, optical or magnetic properties.

Ultimately, produce composite materials of high value in space for use on the ground.

1.4.1.1.2 Description. Equipment required for the Composite Materials experiment is listed below.

a. Basic Units

 B-02 Environmental Chamber "A" - Passive Cooling
 B-03 Environmental Chamber "B" - Passive Cooling
 B-06 Liquid Metal Supply System
 B-08 Instrumentation and Control Center
 B-09 Atmosphere Supply and Control System
 B-10 Power Conditioning and Distribution System

b. Internal Units

I-01 Resistance Heated Furnace - 1600°C
I-06 Mold Injection System
I-08 Dispersion Control System
I-22 Molds, Cavities, Crucible Sets
I-23 Miscellaneous Internal Attachments

c. External Units

E-07 Mixing Unit - Liquid/Solid, Liquid/Liquid
E-10 Vibrator
E-18 External Molds and Container Sets
E-19 Minor External Components

d. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-04 Materials Analysis Equipment
S-06 Open Materials and Fluids Storage

Optional or occasionally used equipment for this experiment includes:

a. Basic Units

B-04 Environmental Chamber "C" - Active Cooling
B-07 General Purpose Laboratory Installation

b. External Units

E-03 Chill System
E-09 Slip Cast Injection System
E-17 VHF Power Unit

c. Support Units

S-01 Process Control Computer
S-05 Photographic Processing Laboratory
S-08 Accident Control System

This class of experiments includes the casting or formation of five types of composite materials:

a. Fiber-reinforced composites

b. Particle-dispersed composites

c. Cemented compacts

d. Controlled eutectic structures

e. Controlled monotectic structures

Two basic types of processing technique are visualized for these materials:

a. Melting, mixing, and controlled solidification of materials which are fluid at the processing temperature.

b. Techniques equivalent to infiltration of a bed of solid particles with a liquid metal matrix.

Fiber-reinforced composites, including those reinforced by whiskers, will be formed by methods which seek to produce controlled preferential orientations of the fibers in the melt. Infiltration methods will be used for compositions containing long fibers or large fiber contents. For compositions containing short fibers, alignment may be achieved by the shear forces generated by special mixing techniques or by acoustic irradiation of the melt.

Particle-dispersed composites will be formed by mixing methods designed to produce uniform dispersions. In the absence of buoyancy, settling, and thermal convection, these dispersions will remain stable when mixing ceases, and it is expected that desirable particle distributions can be retained in the solid state by appropriate control of the solidification process. It is also expected that the grain structure of the metal matrix can be controlled and desirable microstructures can be achieved by the inclusion of particles which nucleate grain growth.

Cemented compacts are composites in which particles of refractory materials such as carbides, borides, and binary hafnium compounds are bound together by a matrix of a metal with a lower melting point. These will be made by a process equivalent to infiltration, known as liquid-phase sintering: combinations of refractory particles and matrix metal particles will be heated above the metal's melting point, so that the liquid metal will coat the refractory particles and bond them together when the mass is cooled.

Controlled eutectic structures will be produced by directional freezing of molten eutectic alloys. The advantage expected from processing in space is that more perfect and continuous structures can be produced when heat and mass transfer due to convection in the melt are suppressed.

In the liquid state a monotectic alloy consists of two immiscible melts of different density, which always separate on Earth. In free-fall is should be possible to produce stable mixtures of immiscible melts with varying cell sizes and shapes, and to obtain novel composite materials by solidifying them. Mixtures of monotectic alloys

will be made by mechanical and acoustic agitation and, where feasible, by precipitation from homogeneous melts obtained by heating the components to temperatures where they are mutually soluble.

Basic operations required of the crew to perform experiments of these types will include setting up appropriate combinations of heating, mixing, and casting equipment with the necessary instrumentation, placing prepared samples of material in the apparatus, and applying prescribed temperature programs and sequences of mechanical manipulations to them. The latter will be applied by automatic equipment which the crew will program and monitor. At the conclusion of an experimental run the crew will clean and secure the apparatus.

In general, the crew will not be required to prepare samples because supply flights will be frequent enough to permit preparation on the ground without inconvenience. However, the crew will perform metallographic examinations and other simple, preliminary sample evaluation tests to criticize the results of some of the experimental runs and determine the need for repetitions or changes of process conditions.

1.4.1.1.3 Observation and Measurement Program. For this class of experiments the space laboratory will be employed essentially as an extension of the facilities available to metallurgical laboratories working on mechanisms of composite material formation and attempting to develop advanced composites. After an initial phase of apparatus testing and technique development, the experiments will concentrate for a time on fundamental aspects of solidification and interactions between the components of composites. Results obtained in this period are expected to apply to composites manufactured on the ground as well as to producing new materials in space.

As prospects for making composite material products in space become more definite, the space experiment program will include an increasing level of development activity in parallel with a fairly constant level of continuing research. The initial level of activity is estimated at 24 to 60 runs per year, and development activities may approximately double these numbers after three or four years.

Data from the experiments will consist primarily of process conditions measured during the runs, laboratory notes by the crew, some photographs of metallographic sections, and the samples themselves. Since process conditions will be slowly varying, adequate information can be provided to experimenters on the ground by transmission in near-real-time. In the event that the conditions go out of limits, however, the control system in the spacecraft should transmit an alarm to the ground at the same time as to the crew, and data transmission should go over to a real-time basis.

Provisions should be made for voice conference between the crew and scientists on the ground, and for TV transmission of selected enlarged portions of metallographic photos. Television resolution is not expected to be adequate for complete evaluation

of metallographic sections prepared onboard the spacecraft, however. Hard-copy records of recent experiments should also be made available to the crew.

1.4.1.1.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.1.1.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods (Section 1.4.1.1.2). The required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
23 Metallurgist
24 Materials Scientist

b. Supporting Skills

8 Photographic Technician
10 Electronic Engineer

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.1.1.6 Available Background Data

a. Processes for Space Manufacturing, Final Report, NAS8-24979, Convair division of General Dynamics.

b. Sphere Forming and Composite Casting in Zero-g, Final Report, NAS8-21402, Arthur D. Little, Inc.

c. Space Processing and Manufacturing, ME-69-1, Oct. 21, 1969.

d. Unique Manufacturing Processes in Space Environment, ME-70-1, April 1970, from Seventh Space Congress, Cocoa Beach, Fla., April 23, 1970.

e. Liquid Phase Sintering in Space, First Quarter Report, Contract NAS8-25053, Oct. 1969.

f. Investigation of the Preparation of Materials in Space, Final Report, Contract NAS8-24683, General Electric.

1.4.1.2 Metal Foams and Controlled-Density Materials

1.4.1.2.1 Scientific and Technical Objectives. Evaluate the stability of distributions of gas bubbles in weightless melts of various metals.

Develop methods of producing controlled distributions of closed (i.e., not interconnected) bubbles with controlled sizes in molten metals and metal-matrix composite materials.

Ultimately, produce stock and fabricated parts of metals and composite materials lightened by controlled distributions of closed bubbles.

1.4.1.2.2 Description. Equipment required for this experiment is listed below:

a. Basic Units

B-02 Environmental Chamber "A" - Passive Cooling
B-03 Environmental Chamber "B" - Passive Cooling
B-06 Liquid Metal Supply System
B-07 General Purpose Laboratory Installation
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-01 Resistance Heated Furnace, 1875°K (1600°C)
I-06 Mold Injection System
I-07 Dispersion Control System
I-22 Molds, Cavities, Crucible Sets
I-23 Miscellaneous Internal Attachment Sets

c. External Units

E-08 Mixing Unit - Liquid/Gas
E-10 Vibrator
E-17 VHF Power Unit
E-18 External Molds and Container Sets
E-19 Minor External Components

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-04 Materials Analysis Equipment
S-05 Photographic Processing Laboratory
S-06 Open Materials and Fluids Storage

1.4.1.3.6 Available Background Data

a. Processes for Space Manufacturing, Final Report, NAS8-24979, Convair division of General Dynamics.

b. Space Processing and Manufacturing, ME-69-1, October 21, 1969.

c. Unique Manufacturing Processes in Space Environment, ME-70-1, April 1970, from Seventh Space Congress, Cocoa Beach, Fla., April 23, 1970.

d. Investigation of the Preparation of Materials in Space, Final Reports, Contract NAS8-24683, General Electric.

1.4.1.4 Liquid Dispersions

1.4.1.4.1 Scientific and Technical Objectives. The reduced-gravity effects on materials behavior in space is important for mixing processes which simultaneously involve liquid/liquid or liquid/solid phases. Whereas two phases may tend to separate due to density differences under the influence of gravity on Earth, they will not tend to separate in space. The improved stability of mixtures of solid particles within the predominant liquid phase will be useful for all manufacturing processes that deal with liquid dispersions. In addition, mixtures of normally immiscible couples can be contenplated.

In the first category, slip casting of metal systems can be considered exemplificative of manufacturing processes involving liquid dispersions. Although the slip casting of metals is known and practiced in present technology, the slips are limited in stability, extremely viscous, and restricted in volume. Slip casting at zero gravity will offer no such restrictions to processing and can prove invaluable for securing large, intricate shapes of materials which are presently difficult, costly, or impossible to fabricate.

Mixtures of immiscible systems provide an opportunity to obtain combinations of materials generally not producible on Earth. A large number of metal-metal and metal-oxide or other pseudobinary systems normally separate when melted and solidified on Earth. Space processing provides a unique opportunity to prepare various combinations of such material systems and to initially secure samples for subsequent characterization of electrical, structural, or other unique properties.

1.4.1.4.2 Description. Equipment required for Liquid Dispersion experiments is:

a. Basic Units

B-02 Environmental Chamber "A", with Passive Cooling
B-03 Environmental Chamber "B", with Passive Cooling
B-08 Instrumentation and Control Center

b. Internal Units

I-01 Resistance Heated Furnace, 1875°K (1600°C)
I-06 Mold Injection System
I-07 Dispersion Control System
I-22 Molds, Cavities, Crucibles (Sets)

c. External Units

E-03 Chill System
E-07 Mixing Unit - Liquid/Solid, Liquid/Liquid
E-09 Slip Cast Injection System
E-10 Vibrator
E-17 VHF Power Unit

d. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-04 Materials Analysis Equipment
S-06 Open Materials and Fluids Storage

Optional or occasionally used equipment for this experiment is:

a. Basic Units

B-04 Environmental Chamber "C", with Active Cooling
B-06 Liquid Metal Supply System
B-07 General Purpose Laboratory Installation
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-02 Furnace, 2875°K (2600°C) - Inert/Vacuum
I-23 Miscellaneous Internal Attachments (Sets)

c. External Units

E-18 External Molds and Containers (Sets)
E-19 Minor External Components (Sets)

d. Support Units

S-01 Process Control Computer
S-05 Photographic Processing Laboratory
S-08 Accident Control System

Slip casting requires a suitable slip and a porous mold. The slip must be stable, contain a high volume fraction of solids, must release easily and not react with the

mold walls and thus limit mold life. The mold must perform the function of liquid removal and shaping of the final cast body. Molds of potting plaster fill these requirements and are almost universally used.

Although any metal could be used for space studies, tungsten would appear ideal since it is processed in powder form (no known practical casting methods are available), has a high density which limits its ability to be slip cast at normal gravity, and is difficult to fabricate, especially as intricate shapes of large dimensions.

Processing of immiscible systems requires that the materials be intimately dispersed while they are in the liquid state. One method is to heat the materials above their consulate temperature where the system consists of a single-phase homogeneous system. If this is not feasible, the materials can be melted and the immiscible liquids dispersed by ultrasonic vibration or other means of agitation. There are many immiscible systems that could be utilized, but from the standpoint of securing materials with potentially unique characteristics, the systems copper-lead, germanium-germanium oxide, and gallium-bismuth are examples being considered.

1.4.1.4.3 Observation and Measurement Program. Crew support will be needed to perform and evaluate each step of the process because conditions for each run will be highly dependant on the success of proceeding steps or complete runs. Essential steps of the slip cast experiments encompass the following:

a. A suitable tungsten slip will be formulated and stored in a nonporous container.

b. A mold of representative complexity (such as a hollow turbine vane or blade) will be cast.

c. Casting at zero gravity proceeds by thoroughly mixing the slip, forcing the slip into the mold by a piston, and allowing casting to take place.

d. After a suitable casting time, the mold is opened, excess slip strained out, and the casting dried.

e. The completed casting (sufficient green strength) will be stored until recovery.

f. Final sintering will be completed after recovery.

Essential steps in the preparation of mixtures of immiscible systems are as follows:

a. A preformed powder compact or segregated casting of the materials to be mixed is inserted into a mold.

b. The mold is heated to the requisite melting temperature, and the materials are outgassed and dispersed. The method of dispersion will be dictated by the materials that are to be processed.

c. After the materials have been dispersed, the mold and contents are cooled to room temperature and the material removed and stored for subsequent evaluation.

Power and spacecraft interface requirements are moderate. The primary process requirement is that the materials be carefully outgassed and well dispersed to ensure a void-free, homogenized mixture.

1.4.1.4.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1 and the pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.1.4.5 Potential Role of Man. Crew functions during experiment performance are indicated by the operational steps discussed in Section 1.4.1.4.3. The required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
23 Metallurgist
24 Materials Scientist

b. Supporting Skills

6 Physicist
10 Electronic Engineer

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.1.4.6 Available Background Information

a. A. Gatti and L. R. McCreight, Slip Casting in Space, NASA Experimental Proposal (Form 1346), 12 December 1969.

b. J. L. Reger, M. E. Kirkpatrick and R. L. Hammel, Reduced Gravity Processing of Homogenized Immiscible Metal Alloys, presented at the Space Processing and Manufacturing Conference, NASA/MSFC, October 21, 1969, NASA Report No. N70-14651.

c. K. P. Staudhammer and L. E. Murr, Thermally Activated Nucleation and Faceting in Immiscible Cu-Cr Thin Films, presented at the 28th Annual Proceedings EMSA, 1970.

1.4.2 CRYSTAL GROWTH

1.4.2.1 Crystal Growth from Solution

1.4.2.1.1 Scientific or Technical Objectives. Crystal growth from solution represents technically and experimentally, one of the simplest methods for the growth of a number of crystalline forms. Potentially, the space environment may produce unusual solution growth phenomena because of the reduction of the buoyant force and thermal convection. The Crystal Growth from Solution experiments should demonstrate the improvements that will occur in space.

It will be important to first determine which crystal growth phenomena are affected by the space environment, using experiments with controlled variation of growth parameters such as rate of cooling, mixing, mechanical vibration, growth time, etc. A proposed flight experiment would define promising aspects of solution crystal growth in the space environment for future investigation, and provide quantitative information about solution crystal growth parameters determined to have an effect on crystal growth in a reduced-gravity field.

The objective of a second experiment would be to study the distribution of "dopant" material in crystals grown under space conditions and to compare the uniformity of this distribution with that of crystals grown, using similar techniques, on Earth. Since the uniformity of dopant distribution in electronic crystals is a relatively important factor in the performance of these materials and of devices which utilize them, the results of this experiment could lead to commercial process development.

The objective of a third experiment is to grow large single crystals of the high density electronic materials by solution growth from molten silicates. For example, one experiment may be to grow a single crystal of potassium sodium niobate in a potassium sodium silicate solvent. Many of the complex oxide-type crystals are hard or impossible to grow in a large single crystal because of their high density. Some of the materials are grown on Earth but with problems due to gravity and convection. It is expected that the piezoelectric, ferroelectric, dielectric, magnetic and electro-optic properties of many ceramic materials would be greatly enhanced by a larger single crystal form.

1.4.2.1.2 Description. Equipment required is:

a. Basic Units

B-03 Environmental Chamber "B" - Passive Cooling
B-07 General Purpose Laboratory Installation
B-08 Instrumentation and Control Center

b. Internal Units

I-01 Resistance Heated Furnace, 1875°K (1600°C)
I-13 Susceptor for Silicon Melts
I-15 Seed Injector
I-22 Molds, Cavities, Crucibles (sets)

c. External Units

None

d. Support Units

S-03 Cleanup and Refurbishment Equipment
S-04 Materials Analysis Equipment
S-06 Open Materials and Fluids Storage
S-08 Accident Control System

Optional or occasionally used equipment includes:

a. Basic Units

B-02 Environmental Chamber "A" - Passive Cooling
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-23 Miscellaneous Internal Attachments (Sets)

c. External Units

E-04 Motion Picture Camera
E-05 TV Camera
E-19 Minor External Components (Sets)

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-05 Photographic Processing Laboratory

Since the purpose of this experiment is to grow both single and multiple crystals under a variety of conditions, a number of samples will need to be heated and cooled. The experiments are designed to study materials such as $NH_4Al_2(SO_4)_3 \cdot 12H_2O$ and $Ni(SO_4)$ grown in an aqueous solution within a temperature range of 293 to 363°K (20 - 90°C). On certain tests, employing growth by a chemical mechanism rather than a thermal mechanism, a constant-temperature environment would be required.

Single-crystal gallium arsenide will be grown in a liquid gallium solution under different growth conditions as part of experiment M512 for Skylab I. Doping the single crystal grown from solution can be accomplished by adding the dopant to the liquid solution. A sequence of experiments can be envisioned in which the chemical and physical properties of the grown crystals could be altered by modifying the growth conditions.

The fused silicate solution growth can be accomplished with or without a single crystal seed. In both techniques the approximate chemicals with the crushed silicate material will be prepared preflight by loading the correct ratio into a platinum crucible. The astronaut would place the crucible into the furnace, and raise the temperature to approximately 1675°K (1400°C) for 12 hours to insure homogenization. Without a seed, a fixed cooling rate will be programmed into the temperature controller. If a seed is used, a technique will be required to insert the seed into the melt before cooling begins. After the crucible is removed from the furnace, the glassy matrix is dissolved from around the crystal. The size and perfection of the grown crystals are determined and the results used to adjust the conditions of the next experiment.

1.4.2.1.3 Observation/Measurement Program. Each experiment will involve the following stages:

a. The astronaut would activate the experiment unit and place a sample holder in the unit.

b. The experiment unit would then heat the sample to ensure that all material is in the liquid phase.

c. Peltier devices would then cool the sample at a given rate.

d. Time-lapse photography of the cell may be initiated.

e. During the cooling process the samples would reach solution saturation and crystal growth would be initiated. Two modes of growth initiation would be employed:

 1. Growth from a seed crystal (to produce a single crystal).

 2. Spontaneous nucleation (to produce multiple crystals).

f. After a fixed period of time the solution growth would be stopped.

g. This sample would then be stored for return to Earth and a new sample inserted for a new experiment.

It will be necessary to have continuous real-time temperature measurements by recorder and/or hourly measurements by a crew member. Some evaluation equipment for physical, electrical, optical, and x-ray analysis of the crystals should be provided.

1.4.2.1.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile III as shown in Figure 1-8 (Section 1.5.4).

1.4.2.1.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods. The required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
24 Materials Scientist

b. Supporting Skills

8 Photographic Technician
10 Electronic Engineer
14 Optical Technician
15 Optical Scientist
25 Physical Chemist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.2.1.6 Available Background Data. Background information for the first solution growth experiment can be found in "A Proposed Crystal Growth Program for Space Processing Including Flight Experiment" January 1970, located at S&E-SSL-TR. MSFC Contact: Mr. T. C. Bannister, S&E-SSL-T, 453-3090.

"Zero-gravity Crystal Growth", Dr. Robert Mazelsky, Westinghouse Electric Corporation, presented at the Space Processing and Manufacturing Symposium held at MSFC, October 21, 22, 1969. MSFC Contact: Mr. Paul Schuerer, S&E-ME-MX, 453-5083.

General Electric Final Report for contract NAS8-24683, control number DCN 1-9-54-20055 and S1(1F). MSFC Contact: Mr. Rudolf Ruff, S&E-ASTN-MEV, 453-3532.

1.4.2.2 Single Crystal Growth from Melts

1.4.2.2.1 Scientific or Technical Objective. The objective of this research area is to produce larger and more perfect crystals by growing from the liquid phase of the crystal. Materials to be used will include:

a. Metals, such as aluminum.

b. Elemental semiconductors, such as silicon.

c. Compound semiconductors, such as III-V or II-VI compounds.

d. Electro-optical materials.

The anticipated benefits will arise from reduced thermal convection at the solid-liquid interface which will result in diffusion controlled solidification.

1.4.2.2.2 Description. Equipment required is:

a. Basic Units

B-02 Environmental Chamber "A" - Passive Cooling
B-03 Environmental Chamber "B" - Passive Cooling
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-11 Zone Melter
I-12 Czochralski Crystal Puller
I-23 Miscellaneous Internal Attachments (Sets)

c. External Units

E-04 Motion Picture Camera
E-05 TV Camera
E-06 Remote Measuring - Mass Dimensions
E-11 Microscope Stage Attachment
E-15 Model Zone Refiner
E-17 VHF Power Unit

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-04 Materials Analysis Equipment
S-05 Photographic Processing Laboratory
S-06 Open Materials and Fluids Storage
S-08 Accident Control System

Optional or occasionally used equipment includes:

a. Basic Units

B-01 Controlled Atmosphere Chamber
B-04 Environmental Chamber "C"; Active Cooling
B-07 General Purpose Laboratory Installation

b. Internal Units

I-04 Heating and Positioning Coils

c. External Units

E-01 Continuous Atmosphere Analysis Apparatus
E-02 High Temperature viewing device
E-19 Minor External Components (Sets)

The following techniques will be used to grow the crystals and understand the solidification phenomena in space.

A modified Czochralski pulling technique suitable for space flight will be used to grow single crystals of various materials. Although the flight design will be considerably automated, it will include facilities for visual observation by the crew and ease in operation. The crew should be able to apply corrective devices if needed. The specimen will be melted in a compatible crucible and a seed crystal will be brought into its contact. Parameters which the crew will be able to manipulate include growth rate, crystal diameter, and thermal gradient at the solid-liquid interface. The furnace chamber should include a television camera so that the interface shape can be photographed intermittently. Desired temperature for the initial experiment will be 1075 to 1675°K (800 to 1400°C). Pulling through ceramic orifices is planned; the possibility of pulling through an electromagnetic field device to avoid all contact contamination is also planned.

Floating-zone growth of a refractory metal should be possible in space. The traveling molten band in the metal rod will be heated by a source such as an electron beam.

Knowledge of the interface behavior between the solid and liquid during crystallization is vital to the interpretation of any results obtained from a space solidification experiment. The purpose of this flight experiment is to obtain time-lapse photomicrograms and temperature data on liquid interfaces in zero-g.

A single crystal of a semiconductor, grown and doped with electrically active impurities on Earth, will be partially remelted and solidified in space. The resulting crystal will provide a direct comparison of growth characteristics that occur on

Earth and in space. In particular, a more homogeneous distribution of the dopant should be achievable in a reduced-gravity environment.

1.4.2.2.3 Observation/Measurement Program. The astronaut must be able to observe the solid-liquid interface during the crystal pulling operation. Using the characteristics of this interface as a guide, the astronaut would adjust the temperature set point of the furnace. This temperature should be displayed on a strip chart for astronaut use in setting up succeeding experiments. After preparing a section of each pulled crystal, the astronaut will analyze the homogeneity of the crystals under a phase-contrast microscope.

The floating-zone experiment will require the astronaut to set up, start, and observe the operation of the experiment. The experiment consists of a set of interchangeable test cells (specially designed specimen containers) which the astronaut would insert into a holder assembly having two Peltier heat sink sources. These heat sources are manually programmed to establish an initial thermal boundary condition for a predefined experimental run. During the run, the growth is observed through a microscope which has an eyepiece for the experimentor (astronaut) and to which is attached a 16 mm time-lapse movie camera; EFB color film is to be used. The light source is a point-source arc bulb with a polaroid filter. The polarized light produces color images which result from the birefringency of the sample in the test cell. Runs would be of 5 to 15 minute duration in which two frames/second would be made. It is planned to observe and track the progressing interface with the use of mirrors so that the test cell and optical system will be stationary; any cell movement would disrupt zero-gravity, and it would also be undesirable to move the optical/photographic system.

A cylindrical bar of single crystal silicon will be placed within the furnace. The heating elements will be wound such that initially heat will be applied to one end of the bar. After this end is melted, the heating zone will travel to half-way down the bar. Cooling will also be directional by cooling the center section of the bar first and the end last. The astronaut will have to cause the heating zone to move along by turning switches on and off, activating a motor-controlled variable resistance or some other device. It is preferred that the experiment operation proceed by watching temperature-monitoring devices rather than by a strict timetable, so astronaut judgement will be necessary.

1.4.2.2.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.2.2.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods. Required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
23 Metallurgist
24 Materials Scientist

b. Supporting Skills

8 Photographic Technician
10 Electronic Engineer
14 Optical Technician
15 Optical Scientist
25 Physical Chemist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.2.2.6 Available Background Data

a. Dr. U. Roy, Single Crystal Growth in Space Environment, Interim Report, University of Alabama at Huntsville (1970).

b. A Proposed Crystal Growth Program for Space Processing Including Flight Experiments, S&E-SSL-TR, Mr. T. C. Bannister.

1.4.2.3 Crystal Growth from Vapor

1.4.2.3.1 Scientific or Technical Objectives. Strong consideration is being given to the possibility of improved crystal growth by vapor transport at zero-g. Crystal growth from a gas phase is accomplished by transporting the atoms from an evaporating source through an inert gas medium to a cooler region where the atoms condense into a single crystal. The gas transport takes place partly by atomic diffusion and partly by convection due to the temperature gradients and gravity.

In a 1-g environment both diffusion and convection cooperate to transport atoms to their growth site. In the absence of gravity, diffusion would be the only transport mechanism, so studies are being concentrated on diffusion in a temperature gradient, both with and without convection. An important question is the relative magnitude of pure diffusion transport compared to convection transport. This question will be answered by a flight experiment.

1.4.2.3.2 Description. Equipment required is:

a. Basic Units

B-03 Environmental Chamber "B" - Passive Cooling
B-08 Instrumentation and Control Center

b. Internal Units

I-01 Resistance Heated Furnace, 1875°K (1600°C)

c. External Units

E-04 Motion Picture Camera
E-05 TV Camera
E-12 Photometric Densitometer

d. Support Units

S-01 Process Control Computer
S-04 Materials Analysis Equipment
S-05 Photographic Processing Laboratory
S-06 Open Materials and Fluids Storage

Optional or occasionally used equipment includes:

a. Basic Units

B-01 Controlled Atmosphere Chamber
B-04 Environmental Chamber "C"; Active Cooling
B-07 General Purpose Laboratory Installation
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-02 Furnace, 2875°K (2600°C) - Inert/Oxygen

c. External Units

E-19 Minor External Components (Sets)

d. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-08 Accident Control System

A tubular gradient furnace about 10 cm (4 in.) in diameter and about 20 cm (8 in.) long will be used to grow whiskers and deposit thin films. Measuring the rate of increase

of film thickness will provide information on the rate of mass transport via a vapor in zero-g. Experimentally obtained diffusion rates are seldom in agreement, and this experiment will support experiments being done on Earth as well as those proposed for space.

Circulating convection currents that occur during vapor transport on Earth have an adverse effect on whisker crystal growth. Excessive supercooling results in massive nucleation, and polycrystals are grown rather than the preferred single crystals. Single-crystal whiskers are also destroyed or damaged as they grow on Earth because of the forces due to gravity.

1.4.2.3.3 Observation/Measurement Program. The approach to the observation of this basic solid-gas phase phenomenon is the observation of crystal growth under the described conditions by means of a high-power metallographic microscope. This would imply the application of a long-distance objective. This technique would not only allow the determination of growth rates of macroscopic faces but it would enable one to record growth velocities and to observe changes in preferential growth directions at a much earlier state in the growth process of a crystal. It is quite conceivable that the growth properties and hence the growth mechanism are of a microscopic size. Experimental data of this type are of great scientific and technological value for substantiating and expanding present theories on the formation of crystal defects. Experimental results would thus be of immediate technological relevance. The method is dependent upon the availability of an onboard metallograph.

In the event that no metallograph is on the spacecraft, the observation of crystal growth can be achieved in a rather simple way by means of a commercially available camera with close-up lens. The camera could be programmed in such a way that a photographic record of the growing crystal is obtained at regular time intervals. These data would provide information concerning the relative growth velocities of crystal faces and the possible change in growth rates of different faces as a function of transport conditions. Since these experiments would be performed in a zero-gravity environment, convection currents are completely eliminated. The observed growth rates are based strictly on ideal diffusion conditions and represent, therefore, true equilibrium data. Such information is of fundamental importance for the understanding of nucleation and condensation phenomena.

It may be desirable to examine the whiskers only after they have been grown. In this case, each growth tube could be carefully removed from the furnace, with minimum

vibration, to the field of view of a microscope. The tube would be arranged so that it could be either rotated about its axis or translated along its axis, thus allowing the whole tube to be scanned without moving the microscope. Some slight optical difficulty is encountered in viewing a specimen through a curved glass tube. However, by applying a slight rotation to the tube, the whiskers may be brought into focus. Astronauts would have observed whiskers grown under the exact conditions, except at 1-g. At zero-g they would look for longer, thinner whiskers. Photomicrograms are planned with onboard photo equipment.

1.4.2.3.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.2.3.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods. Required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
23 Metallurgist
24 Materials Scientist

b. Supporting Skills

8 Photographic Technician
10 Electronic Engineer
14 Optical Technician
25 Physical Chemist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.2.3.6 Available Background Data

a. Dr. J. H. Davis, Interim Report, The Effect of Gravity on Crystal Whiskers, University of Alabama at Huntsville (1970).

b. Preliminary Proposal for Modifying the Westinghouse Zero-g Furnace for Whisker Growth, Marshall Space Flight Center, S&E-SSL-T.

1.4.2.4 Supercooling and Homogeneous Nucleation Experiments

1.4.2 4.1 Scientific and Technical Objectives

a. Determine the kinetics of nucleation and grain growth in pure elements, alloys, and compounds as functions of supercooling.

b. Directly test the theory of homogeneous nucleation and provide data which may be used to extend it.

c. Develop new understanding of the liquid-solid transition and the kinetics of short-range ordering in liquids.

d. Derive accurate values for solid-liquid interface energies in melts.

e. Provide a basis for ultimate development of methods for rapid production of large single crystals of high-purity materials.

1.4.2.4.2 Description. Equipment required is:

a. Basic Units

B-01 Controlled Atmosphere Chamber
B-03 Environmental Chamber "B"; Passive Cooling
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control Systems
B-10 Power Conditioning and Distribution System

b. Internal Units

I-11 Zone Melter
I-14 High Temperature Calorimeter
I-16 Internal Friction Measuring Device

c. External Units

E-01 Continuous Atmosphere Analysis Apparatus
E-06 Remote Measuring - Mass Dimensions

d. Support Units

S-04 Materials Analysis Equipment
S-06 Open Materials and Fluids Storage

Optional or occasionally used equipment is:

a. Basic Units

B-04 Environmental Chamber "C"; Active Cooling

b. Internal Units

I-04 Heating and Positioning Coil Sets
I-23 Miscellaneous Internal Attachments

c. External Units

E-02 High Temperature Viewing Device
E-05 TV Camera
E-17 VHF Power Unit
E-19 Minor External Components

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-05 Photographic Processing Laboratory
S-08 Accident Control System

This experimental effort will attempt to produce relatively large samples (of the order of 1 cm^3 in volume) of various materials with purity such that they can be supercooled to temperatures where homogeneous nucleation occurs. By melting and cooling samples of several different sizes at relatively slow rates, we expect to be able to measure the nucleation rate directly as a function of temperature. From such data, fundamental information such as the sizes of critical nuclei and solid-liquid interface energies can be derived. When the experimental conditions are brought under sufficient control, it should also be possible to produce single crystals whose growth is initiated by a single homogeneous nucleation event. Since growth velocities of the order of a meter per second are obtained with supercooling of the order of 100°K (100°C), such a process might be capable of producing large single crystals at relatively high production rates.

The experimental setup will consist of several different pieces of apparatus, mounted at different stations in the large vacuum/controlled atmosphere chamber, with an electromagnetic positioning/handling system that can pass the samples from one station to another without contacting them. The samples will be small bars of material, about 10 cm long and 0.5 cm in diameter, which have been purified to the highest degree possible on the ground.

At the first station in the chamber, the sample to be used in a given experiment will be further purified by floating-zone refining. Heating of the molten zone will be by electromagnetic induction or electron bombardment, and the sample will be levitated in the apparatus, with no physical contact at any point. The zone refining installation will include a shaping coil system to control the shape of the molten zone so that the ignot dimensions will not change; depending on the circumstances, from 10 to 100 zone melting passes may be required.

At the time of the purification process the purest part of the ingot will be separated from the remainder by melting zones at appropriate points and using the zone refiner's positioning coil system to pull the ingot apart. This part of the ingot will be the sample for the supercooling experiments; it will be transferred to a second station in the apparatus where it will be remelted and allowed to assume a spherical shape, after which its mass and dimensions will be determined.

Observations of supercooling and homogeneous nucleation will be performed at either or both of two additional stations. One of these stations will comprise an internal friction apparatus, where the molten sample will be levitated in a coil system that will maintain it in an appropriately selected mode of resonant oscilliation while it is cooled. The onset of nucleation will be detected by changes in the dynamic behavior of the oscillating drop, and it is expected that short-range ordering effects preceding nucleation can be studied by determining the shapes of internal friction peaks.

The other data-taking station will be a differential calorimeter in which the beginning of solidification will be detected by observing the accompanying thermal arrest, and the rate of release of the heat of fusion will be measured. The latter measurement is expected to indicate how many nucleation sites are effective.

Most of the purification and experimental observation sequences will be performed under automatic control, and the main functions of the crewmen operating the apparatus will be in setting it up, programming the controls, monitoring critical steps, and securing the apparatus.

Setup time may take from one to three hours, during which the crewman will set up the apparatus in the appropriate configuration, check its functioning, introduce a bar of sample material, and program the controls to produce prescribed conditions for the purification process. The zone melting runs will require from 50 to 500 hours, depending on the number of passes, but will need to be checked only two or three times a day.

Separation of the sample from the rest of the ingot will take about half an hour and should be monitored continuously. Operations at the measurement station will be completely automatic and will require no attention beyond checking that the device functions properly.

The first step of a data-taking run in either the differential calorimeter or the internal friction apparatus will be a heating cycle, about an hour long, in which the sample will be melted and thermally equilibrated. Usually the second step will be a rapid cooling cycle lasting a few minutes, in which the nucleation temperature will be roughly determined and the general characteristics of the nucleation process will be surveyed. Programming for the second cooling cycle will be determined by the operating crewman in consultation with scientists on the ground. In this cycle the sample will be remelted and equilibrated, cooled rapidly to a selected temperature

somewhat above the nucleation temperature, and cooled slowly through the nucleation temperature to obtain exact data. In most of the runs one or two additional heating and cooling cycles will be performed to refine the data further and/or to attempt solidification from a single nucleation event. About half of the runs will be followed by operations in which the sample will be transferred back to the zone melting station, converted into bar form, and subdivided into smaller pieces for further melting and cooling runs involving different nucleation temperatures.

At the end of a sequence of runs the crewman will secure the samples in containers, clean the apparatus, and either dismantle the experimental setup to leave the chamber free for other work or else secure it in readiness for the next sequence.

Sample evaluation following performance of the experiment will include measurements of sample weights and dimensions and in some cases sectioning and metallographic examination of grain structures on board the spacecraft. Other evaluation procedures will be performed on the ground.

1.4.2.4.3 Observation and Measurement Program. Operation of this type of experiment will support research programs conducted by multiple investigators on the ground and will be scheduled to coordinate with their efforts. The experimental program will process 10 to 30 samples per year.

Materials to be studied will include elemental metals and semiconductors, some alloys, and a few compounds. In the case of the alloys, the constituents must be refined separately, melted together in selected proportions, and zone leveled in the apparatus prior to data-taking runs. The range of materials that can be studied will be determined by the temperature capabilities of the zone refining and remelting apparatus, which will probably be upgraded as the program progresses. The initial version of the apparatus should reach temperatures up to 2175°K (1900°C) so that ferrous metals and a reasonable selection of transition metals can be studied.

All data from measuring instruments, control settings, etc., will be transmitted to the ground, analyzed by computers, and converted to hard copy in real time for the information of scientists supporting the experiments. Strip chart displays and printouts of processed data will be provided to the operating crewmen, who will dictate their laboratory notes on voice recorders for transmission to the ground and transcription. Provisions should also be made for voice conferences between crewmen and scientists on the ground, and for transmission of hard copy to the crew.

Photographs of metallographic sections made onboard the spacecraft will be processed in space and preliminary analysis will be performed by crewmen. TV transmission of selected enlarged areas of the photographs may be used for consultation with scientists on the ground, but in general TV resolution will not be sufficient for analysis. Originals of all metallographic photographs will be returned to the ground with the samples, and copies will be retained onboard for use by the crew.

1.4.2.4.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile IV as shown in Figure 1-8 (Section 1.5.4).

1.4.2.4.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods. Required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
23 Metallurgist
24 Materials Scientist

b. Supporting Skills

6 Physicist
8 Photographic Technician
10 Electronic Engineer
14 Optical Technician
25 Physical Chemist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.2.4.6 Available Background Information. Chalmers, Principles of Solidification (John Wiley & Sons, New York, 1964), Chapter 3.

1.4.3 GLASS PROCESSES

1.4.3.1 Preparation of Glasses

1.4.3.1.1 Scientific or Technical Objectives. Evaluate the effects of weightless preparation conditions with and without containers on the crystallinity as well as optical and surface properties of conventional glasses and fused oxides.

Develop methods of preparing new glasses, such as oxide systems with low dispersions and high refractive indices, semiconductor glasses with improved hardness and high softening temperatures, and vitreous materials that can be crystallized to form ceramic articles or single crystals.

1.4.3.1.2 Description. Equipment required is:

a. Basic Units

B-04 Environmental Chamber "C"; Active Cooling
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-03 Furnace, 3475°K (3200°C) - Oxygen
I-04 Heating and Positioning Coil Sets
I-05 Plasma Electron Beam Unit

c. External Units

E-01 Continuous Atmosphere Analysis Apparatus
E-02 High Temperature Viewing Device
E-06 Remote Measuring - Mass, Dimensions
E-17 VHF Power Unit

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-06 Open Materials and Fluids Storage
S-07 Controlled Atmosphere Fluids Storage
S-08 Accident Control System

Optional or occasionally used equipment includes:

a. Basic Units

B-02 Environmental Chamber "A"; Passive Cooling

b. Internal Units

I-02 Furnace, 2875°K (2600°C) - Inert/Vacuum
I-23 Miscellaneous Internal Attachments

c. External Units

E-19 Minor External Component Sets

d. Support Units

S-05 Photographic Processing Laboratory

Experiments in this class will seek to define how weightless conditions affect the formation of conventional optical glasses and to explore how containerless processing methods can be used to form glasses from oxide compositions that are normally crystalline. In the first instance, batches of known glass-forming compositions containing carbonates and nitrates will be melted, solidified, and heat-treated under vacuum and oxidizing atmospheres to determine to what extent glasses can be refined and homogenized in free-fall without stirring. In the second case, mixtures of oxides such as Al_2O_3, ZrO_2, HfO_2, and TiO_2 will be melted and solidified by containerless methods. Atmospheres, times, and temperature cycles will be manipulated to suppress homogeneous and heterogeneous nucleation in these materials so as to solidify them in vitreous forms with adequate chemical and optical homogeneity.

Samples with melting points below 2575°K (2300°C) will be heated by electrical radiant heating, and materials requiring higher temperatures will be heated by induction after being preheated by radiation. Levitated samples will be positioned by electrostatic fields or by acoustic radiation pressure transmitted through the surrounding gas at temperatures where the sample resistivity is high. At temperatures where sample resistivities are sufficiently low, positioning will be accomplished by electromagnetic coil systems.

Crew functions in these experiments will mostly consist of technician-type functions: setting up apparatus to provide prescribed atmospheres and other process conditions, running samples of materials supplied from the ground, and refurbishing and securing the apparatus at the conclusion of a run or series of runs. Since the materials will have low vapor pressures, little contamination of the apparatus by deposited material is expected. On the other hand, precise control over the atmosphere surrounding the samples will be essential in many cases, so that close attention must be given to controlling sources of gaseous contaminants in the apparatus.

1.4.3.1.3 Observation and Measurement Program. Glass preparation experiments will be performed in support of a variety of programs on new glasses conducted at glass research laboratories on the ground. The experimental runs will be used primarily to supply samples for evaluation and research by these laboratories, and from 12 to 40 runs will be performed per year.

Since the critical feature of each experiment will be to establish process conditions to produce samples of desired types from mostly unfamiliar materials, the crew will perform an essential function in evaluating the results of each run and helping personnel on the ground to decide on conditions for succeeding runs. Optical apparatus will be provided for onboard evaluation of the homogeneity and degree of crystallinity of samples produced during the runs. All samples will be subject to preliminary evaluation tests by the crew, and facilities will be needed for transmission of photographic data from these tests to the ground, as well as for voice conferences between crew

members and ground experimenters. In addition, all data relating to process conditions will be transmitted following each run. For some special runs, real-time data transmission and TV coverage may be required.

1.4.3.1.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile II as shown in Figure 1-8 (Section 1.5.4).

1.4.3.1.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods. Required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
24 Materials Scientist

b. Supporting Skills

6 Physicist
10 Electronic Engineer
14 Optical Technician
15 Optical Scientist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.3.1.6 Available Background Information

a. Processes for Space Manufacturing, Final Report, NAS8-24979, Convair division of General Dynamics.

b. Space Processing and Manufacturing, ME-69-1, Oct. 21, 1969.

c. Unique Manufacturing Processes in Space Environment, ME-70-1, April 1970, from Seventh Space Congress, Cocoa Beach, Fla., April 23, 1970.

d. Investigation of the Preparation of Materials in Space, Final Report, Contract NAS8-24683, General Electric.

1.4.3.2 Glass Processing

1.4.3.2.1 Scientific and Technical Objectives. Develop processes that take advantage of aspects of weightlessness to produce new or improved glass products with

high purity, high optical homogeneity, improved surface properties, uniform dispersions of special particles, et cetera. Ultimately, use these processes to produce articles such as the following:

a. Low index/low dispersion glasses free from striae.

b. Laser-glass billets having high damage thresholds.

c. Lenses and mirror blanks with high-strength flame-polished surfaces.

d. Large Christiansen filters.

e. Glass filters whose integrated transmission depends on the intensity and/or spectral distribution of the incident light.

1.4.3.2.2 Description. Equipment required is:

a. Basic Units

B-04 Environmental Chamber "C"; Active Cooling
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-03 Furnace, 3475°K (3200°C) - Oxygen
I-04 Heating and Positioning Coil Sets
I-05 Plasma Electron Beam Unit

c. External Units

E-01 Continuous Atmosphere Analysis Apparatus
E-02 High Temperature Viewing Device
E-06 Remote Measuring - Mass, Dimensions
E-17 VHF Power Unit

d. Support Units

S-01 Process Control Computer
S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-06 Open Materials and Fluids Storage
S-07 Controlled Atmosphere Fluids Storage
S-08 Accident Control System

Optional or occasionally used equipment is:

a. Basic Units

B-02 Environmental Chamber "A"; Passive Cooling

b. Internal Units

I-02 Furnace, 2875°K (2600°C) - Inert/Vacuum
I-23 Miscellaneous Internal Attachments

c. External Units

E-19 Minor External Component Sets

d. Support Units

S-05 Photographic Processing Laboratory

Free-fall appears to offer several prospects for developing processes which eliminate or circumvent problems that hinder production of certain specialized optical glass products on Earth. For example, inclusions which lower the damage thresholds of high-power laser glasses are believed to originate from crucibles and other foreign objects in contact with the melt; containerless processing methods might avoid these. Certain optical glasses are difficult to make in large pieces with adequate optical homogeneity, and there is some indication that better results could be obtained with the improved control over heat and mass transport in the melt that could be achieved in free-fall.

Optical surfaces about an order of magnitude smoother than those obtainable by mechanical polishing can be obtained by fire polishing, and are needed in some special instruments. Components of this sort can potentially be made by using external fields to shape the molten glass to the desired figure without mechanical contact. Finally, specialized filters with several types of unique transmission properties can be made by dispersing various kinds of colloidal or larger particles in specific glasses. We expect that such dispersions can be made more uniform in free-fall, and that dispersions can be made which are impossible on Earth.

Initial experiments in this class will concentrate on determining the fundamental feasibility of processing techniques and on elucidating the basic causes of problems such as those outlined above, for not all of them are completely understood. As the technical basis for new products expands, the work will shift toward actual development.

Experimental methods and crew functions will be qualitatively similar to those described in Section 1.4.3.1.2 for preparation of new glasses. The chief differences between the two types of experiment will be that the glass processing work will not

initially operate at the extreme temperatures required to form oxide glasses, and will require a greater variety of apparatus setups. For example, glass processing will rely more on special noncontacting mixing techniques and may involve molding and infiltration methods somewhat like those used to produce composite materials. In addition, these experiments will use external fields to shape glass melts as well as to hold them in position.

1.4.3.2.3 Observation and Measurement Program. Initially, glass processing experiments will be conducted for a user community of glass research workers similar to that for glass preparation. As definite product possibilities are uncovered, however, it is expected that increasing amounts of work will be done in support of product development teams. The initial level of activity is expected to be 6 to 24 experimental runs per year; development activities may eventually raise the total to about 50 runs per year.

Data requirements will be practically confined to recording of process parameters, such as times and temperature cycles, from each run. In view of the sophisticated nature of the sample properties which the experiments will investigate, onboard evaluation will be useful only to determine the gross integrity of the samples.

1.4.3.2.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile II as shown in Figure 1-8 (Section 1.5.4).

1.4.3.2.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods; required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
24 Materials Scientist

b. Supporting Skills

10 Electronic Engineer
14 Optical Technician
15 Optical Scientist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.3.2.6 Available Background Information

a. Processes for Space Manufacturing, Final Report, NAS8-24979, Convair division of General Dynamics.

b. Space Processing and Manufacturing, ME-69-1, October 21, 1969.

c. Unique Manufacturing Processes in Space Environment, ME-70-1, April 1970, from Seventh Space Congress, Cocoa Beach, Fla., April 23, 1970.

d. Investigation of the Preparation of Materials in Space, Final Report, Contract NAS8-24683, General Electric.

1.4.4 BIOLOGICAL PROCESSING

1.4.4.1 Electrophoretic Separation

1.4.4.1.1 Scientific and Technical Objectives. Determine the feasibility and evaluate the advantages of methods for electrophoretic separation of biological preparations in space. When feasible methods have been developed, produce pure vaccines and other biological preparations for medical use and biochemical research.

1.4.4.1.2 Description. Equipment required is:

a. Basic Units

B-05 Biological Enclosure
B-07 General Purpose Laboratory Installation
B-08 Instrumentation and Control Center
B-10 Power Conditioning and Distribution System

b. Internal Units

I-17 Stationary Electrophoretic Column
I-18 Continuous Electrophoretic Column
I-19 Buffer Recovery/Waste Disposal System
I-20 Gas Elimination/Cooling System

c. External Units

E-05 TV Camera
E-13 UV Microdensitometer
E-14 Holographic Interferometer

d. Support Units

S-04 Materials Analysis Equipment
S-07 Controlled Atmosphere Fluids Storage

Optional or occasionally used equipment is:

a. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-05 Photographic Processing Laboratory
S-08 Accident Control System

In the zone electrophoresis technique, mixtures of organic molecules or particles are separated by differential transport through an electric field in a fluid medium. A narrow band of the mixture to be separated is introduced into a column of a buffer solution whose pH is selected so that the molecules acquire various specific electric charges, and a bias voltage is applied between the ends of the column. The organic molecules migrate in the field at different velocities because their charges and mobilities differ, and after a suitable time the original narrow band of molecules becomes separated into a distribution of bands along the length of the column. The components of the original mixture can be withdrawn as they arrive at the end of the column, and individual fractions can be further separated, if necessary, by repeating the process in a different buffer solution.

The technique can also be used in a continuous-flow process. In this case the buffer solution flows slowly along a duct that has a flat, rectangular cross-section, and the electric field is imposed along the long dimension of the duct's cross-section, perpendicular to the direction of flow. The mixture to be separated is introduced continuously through a narrow slit at the upstream end of the duct and is separated by the field as it is carried downstream. The desired fraction or fractions are collected through one or more appropriately placed slits at the downstream end of the duct.

Both types of apparatus will be operated in the Space Station experiment program. The stationary column technique will be used to study fundamental aspects of the process; to determine the charges, mobilities, and diffusion constants of various molecules; and to analyze unknown solutions. The continuous-flow apparatus will be used to develop processing techniques and to produce useful quantities of purified materials.

In either case the functions of crew members operating the apparatus will be similar. To begin an experimental run, the operator will fill the apparatus with buffer made up from stock solutions, set its power supply to provide a specified program of voltage vs. time, and introduce the sample. Samples will be supplied in aqueous solution and may contain pathogenic or highly toxic materials; such samples will be

handled only in the Biological Enclosure, which will be designed to prevent accidental release of hazardous materials and will incorporate systems to detoxify and remove any materials released inside the enclosure. Tests of developmental apparatus outside the enclosure will be conducted only with innocuous sample materials.

In the stationary column apparatus, samples will be small and will be injected into the columns with a syringe-type device. In the continuous-flow apparatus the operating crewman will connect the ampoule containing the sample to the injection system in the apparatus, verify that the buffer is flowing at the correct rate, and initiate sample injection.

A typical run in the stationary column will take 20 or 30 minutes and will need to be monitored by the astronaut. In the continuous-flow apparatus, runs may occupy several hours but will need only intermittent attention after the first half-hour, during which the operator must verify that the desired fractions are being collected as planned. In some cases runs will be monitored visually by means of marker dyes of known mobility, which will be introduced with the samples. In other cases the progress of the separation will be monitored by scanning the column periodically with a Schlieren optical system or a UV microdensitometer.

At the conclusion of a run the operator will flush the apparatus, clean it by using an ultrasonic cleaner included in the installation, with solutions selected to eliminate any hazard from residual sample materials, and secure it in condition for the next run. Since the cleaning materials may themselves be somewhat toxic (for example, phenol may be used), appropriate provisions must be made to secure and dispose of them separately from the part of the waste management system that is connected to the water recovery loop. However, waste materials from biological processing can be mixed with other wastes, such as garbage and feces, and in fact will help retard bacterial growth in them.

Materials separated in the experiments will usually be returned to Earth, but some will have to be assayed onboard by chemical and immunological tests when the progress of a research project can be speeded significantly by so doing. It is anticipated that the Space Station's biological research facilities will be used for such tests. Some samples will be returned to Earth in solution, and others will be preserved by lyophilization (freeze-drying) prior to return.

1.4.4.1.3 Observation and Measurement Program. Experiments in this class will be performed for two purposes:

a. To analyze or purify samples for medical and biological research workers on the ground.

b. To develop separation processes for future large-scale commercial and/or public applications in vaccine purification, etc.

The former type of experiment will be performed with apparatus whose configuration will remain relatively constant after an initial period of "debugging" in space. Since this type of experiment will be performed primarily as a service to biomedical research, the level of activity will be controlled by demand. A minimum of 20 and a maximum of about 80 runs will be performed for such purposes in both the stationary and the continuous-flow apparatus per year.

Process development runs will be less frequent because they will be part of an interative process; runs will usually be separated by intervals in which results must be evaluated, and the developmental apparatus may be modified before the next step can be taken. It is expected that from 50 to 100 runs in stationary columns and from 25 to 50 runs in continuous-flow apparatus will be performed each year for developmental purposes.

Most of the sample evaluation tests to be used in the biological processing program will be tests of the biological activity and the chemical nature and purity of processed materials. Usually these tests will require complex equipment or procedures (e.g., electron microscopy, tests of vaccine effectiveness using animal colonies, etc.) and will have to be done on the ground. However, some "first look" tests can be performed on the spacecraft to reduce the turnaround time between experimental runs. The following is a representative list of onboard sample evaluation measurements:

a. Inspection of Schlieren and microdensitometer traces taken on electrophoresis columns.

b. Infrared absorption spectra of samples.

c. Titration with biological reagents.

d. Measurements of chemical reaction rates involving the products; for example, using enzymes specific to the product.

e. Measurements of effectiveness of toxins, bacteriophages, and similar products by application to bacterial cultures.

f. Immunoelectrophoresis runs on antigenic products.

The experiment program will need to use an onboard biochemical laboratory if much sample evaluation is to be done in flight. Cameras and photographic processing facilities will also be useful to record apparatus setups and general features of

experimental technique. If a general-purpose chemical facility is available it will be used to prepare and characterize the buffer solutions used in electrophoresis work.

Data and record-keeping requirements will be generally the same as for biochemical laboratory work on Earth. Data from measuring instruments will be anlyzed by computer and automatically converted to hard copy in standardized format either on the ground or in space. Crewmen operating the apparatus will dictate their laboratory notes on voice recorders for transmission to the ground and transcription, and transcribed copy will be sent to the Space Station for review and revision via facsimile or teleprinter. Microdensitometer and Schlieren traces (and infrared spectra of samples, if taken) will be sent to experimenters on the ground by facsimile. Provision must be made for periodic voice conferences between crewmen and experimenters.

1.4.4.1.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power Requirements are further represented by power profile III as shown in Figure 1-8 (Section 1.5.4).

1.4.4.1.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods; required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

1 Biological Technician

b. Supporting Skills

2 Biochemist
8 Photographic Technician
10 Electronic Engineer
12 Electromechanical Technician
14 Optical Technician

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.1.6 Available Background Information

a. L. R. McCreight, et al. Investigation of the Preparation of Materials in Space: Quarterly, Monthly, and Final Reports on NASA Contract No. NAS8-24683 (G.E. Space Sciences Laboratory, King of Prussia, Pa., June 1969 - March 1970).

b. R. N. Griffin and L. R. McCreight, Study of Zero-G Fluid Electrophoresis: Monthly Reports on Modification No. 3 of NASA Contract No. NAS8-24683 (G.E. Space Sciences Laboratory, King of Prussia, Pa., May 1970 - January 1971).

c. J. R. Cann, "Recent Advances in the Theory and Practice of Electrophoresis," Immunochemistry, 5, 107-134 (1968).

d. L. Ornstein, "Disc Electrophoresis," Annals of the New York Academy of Sciences, 121, 321-349 (1964).

e. M. Bier, ed., Electrophoresis: Theory, Methods, and Applications, Vol. II (Academic Press, New York, 1967).

f. A. Kolin and S. J. Luner, "Continuous Electrophoresis in Fluid Endless Belts," Analytical Biochemistry, 30, 111-131 (1969).

1.4.4.2 Lyophilization

1.4.4.2.1 Scientific and Technical Objectives. Develop techniques of lyophilization (freeze-drying) of biological materials in a weightless environment and evaluate how the results differ from those of conventional techniques. When developed, use space lyophilization techniques to treat samples for research purposes and to preserve materials prepared by electrophoresis and other biological processing methods.

1.4.4.2.2 Description. Equipment required is:

a. Basic Units

B-05 Biological Enclosure
B-08 Instrumentation and Control Center

b. Internal Units

I-21 Lyophilization Apparatus

c. Support Units

S-07 Controlled Atmosphere Fluids Storage

Optional or occasionally used equipment is:

a. Basic Units

B-10 Power Conditioning and Distribution System

b. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-08 Accident Control System

In the lyophilization process, samples in aqueous solution will be placed in small (about 10 ml) vials, frozen, and dried by exposure to vacuum; after the solid water in the samples has evaporated, they may be heated to drive off bound water. However, a principal advantage of the space process is that the random motions of the Space Station will have the effect of dispersing the partially dried samples inside the vials, thereby exposing maximum surface area and reducing the necessity to heat perishable or partially unstable samples.

If lyophilization apparatus is available as part of the Space Biology or Biomedicine facilities, this would be adequate for the MS/MS program's purposes. Otherwise, the program will provide its own apparatus. In this case, the sample vials will be placed in a holder provided with heat-pumping units, and the holder will be mounted in an airlock. The heat pumps will be operated so as to reduce the sample temperature to about 263°K (-10°C), after which the airlock will be opened to expose the samples to the vacuum of space. After a time of the order of one hour, the heat pumps will be reversed, the sample temperature will be raised to some value not exceeding about 325°K (50°C), and the exposure will continue for about another hour. At the end of the run, the vials will be stoppered by a mechanical actuator and brought inside the spacecraft. The crewman's function in the operation will be to load and unload the sample holder and to set automatic controls that determine time and temperature cycles for each run.

1.4.4.2.3 Observation and Measurement Program. Initial experiments with lyophilization in space will be conducted mainly to develop efficient techniques and to evaluate possible differences in the effects of the process when the materials being treated are levitated and therefore have very large exposed surface areas. When apparatus and techniques are fully developed, the process will be used to preserve some of the materials processed by the electrophoretic separation program and also to investigate the effects of extreme environments on viruses and microorganisms. In the latter type of work, samples will be supplied by experimenters on the ground. The level of activity expected for both purposes will be a minimum of 20 and a maximum of about 100 runs per year, with about 100 sample vials processed in each run.

Data from the experiments will simply comprise records of process conditions in most cases, for the runs will be performed under automatic control and the samples will usually be returned to Earth for evaluation. In cases where highly perishable

samples must be evaluated on board, tests will include culturing of reconstituted microorganisms and evaluations such as those described in Section 1.4.4.1.3 for other biological materials.

1.4.4.2.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.4.2.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods; required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

1 Biological Technician

b. Supporting Skills

2 Biochemist
10 Electronic Engineer
12 Electromechanical Technician

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 and P-24). A general description of individual skills in presented in Section 1.7.

1.4.4.2.6 Available Background Information

a. L. R. McCreight and R. N. Griffin, "Unit Separation Processes in Space," MSFC Report No. ME-69-1, Space Processing and Manufacturing (Oct. 21, 1969) pp. 216-237.

1.4.5 PHYSICAL PROPERTIES OF FLUIDS

1.4.5.1 Convection

1.4.5.1.1 Scientific and Technical Objectives. The primary objective of this group of experiments is to define the role of gravity in fluid transport phenomena. A corollary objective is to generate fundamental data on non-gravity-dependent fluid phenomena which are normally masked by the gravitational effects. These date are applicable to almost all MS/MS processes, since they are involved in some stage of most processes.

1.4.5.1.2 Description. Equipment required is:

a. Basic Units

B-01 Controlled Atmosphere Chamber
B-02 Environmental Chamber "A"; Passive Cooling
B-03 Environmental Chamber "B"; Passive Cooling
B-04 Environmental Chamber "C"; Active Cooling
B-07 General Purpose Laboratory Installation
B-08 Instrumentation and Control Center
B-09 Atmosphere Supply and Control System
B-10 Power Conditioning and Distribution System

b. Internal Units

I-01 Resistance Heated Furnace, 1875°K (1600°C)
I-14 High Temperature Calorimeter
I-22 Molds, Cavities, Crucibles
I-23 Miscellaneous Internal Attachments

c. External Units

E-04 Motion Picture Camera
E-05 TV Camera
E-11 Microscope Stage Attachment
E-12 Photometric Densitometer
E-14 Holographic Interferometer
E-16 Isotope Tracer Counter

d. Support Units

S-02 Heat Rejection System
S-03 Cleanup and Refurbishment Equipment
S-05 Photographic Processing Laboratory
S-06 Open Materials and Fluids Storage
S-07 Controlled Atmosphere Fluids Storage
S-08 Accident Control System

Optional or occasionally used equipment is:

a. Basic Units

B-06 Liquid Metal Supply System

b. Internal Units

I-04 Heating and Positioning Coils

c. External Units

E-06 Remote Measuring - Mars Dimensions
E-07 Mixing Unit - Liquid/Solid, Liquid/Liquid
E-08 Mixing Unit - Liquid/Gas
E-13 UV Microdensitometer
E-15 Model Zone Refiner

Experiments concerning convection will require input from, and have output to, a broad range of the technical and scientific community including metallurgists, liquid state physicists, fluid dynamicists, thermodynamicists, biologists, and chemists. Three basic types of experiments are envisioned:

a. Isolation and measurement of basic fluid properties under static conditions such as surface tension, thermal conductivity, etc.

b. Isolation and measurement of basic fluid properties when important parameters such as temperature, etc., are varied.

c. Study of combined convection effects at fluid interfaces.

An example of type a would be the measurement of thermal conductivity in fluids in various geometric configurations such as radial heat flow, longitudinal heat flow, etc.

An example of type b might be measurement of flow rates under various driving forces or defining the role of convection in heat transfer due to boiling or freezing.

Type c experiments would involve the study of the role of convection at fluid interfaces. The role of convection at the solidification interfaces, for example, will be studied.

In most cases, the experiments will begin with low temperature fluids and evolve to higher temperature fluids. The crew of the spacecraft will generally be required to set up the required control and measurement equipment and monitor the experiment as various parameters are varied. In many cases the samples will be ground prepared, since timely logistics are anticipated, and because of technical requirements such as extreme cleanliness levels.

1.4.5.1.3 Observation and Measurement Program. Experiments of this type will be essentially basic research in nature; however, the experiment program will evolve to a more applied nature. At the outset, basic fluid phenomena measurements will be made in a manner similar to classic investigations. As data are compiled and

verified, the various modes of convection will be defined. As the MS/MS program matures it is anticipated that various application problems involving convection will arise in other areas of the MS/MS program (for example, crystal growth). As these applied problems arise, experimental investiation will be undertaken.

1.4.5.1.4 Interface, Support and Performance Requirements. Requirements are identified in Block C1, and pertinent data in Block C2 of Table 1-2. Power requirements are further represented by power profile I as shown in Figure 1-8 (Section 1.5.4).

1.4.5.1.5 Potential Role of Man. Crew functions during experiment performance are discussed in the description of experimental methods; required skills and the degree of involvement are identified in Table 1-2, Blocks B1 and B2, as follows:

a. Principal Skills

12 Electromechanical Technician
24 Materials Scientist

b. Supporting Skills

6 Physicist
8 Photographic Technician
10 Electronic Engineer
14 Optical Technician
25 Physical Chemist

Cumulative crew times per experiment run are defined in Blocks C1 and C2 of Table 1-2 (lines P-22 to P-24). A general description of individual skills is presented in Section 1.7.

1.4.5.1.6 Available Background Information

a. T. Bannister and G. Arnett, A Proposed Crystal Growth Program for Space Processing Including Flight Experiments, January 1970.

b. Dr. P. G. Grodzka, Zero Gravity Solidification, LMSC D 148619, March 1970.

c. Dr. J. Davis and Dr. U. Roy, Interim Report Number One, Parts A and B, June 1970.

d. K. Knapp and H. Niser, Study of Liquid Drop Dynamics in Zero Gravity, EOS Report 7170-Final, November 1967, Electro-Optical Systems, Inc., NASA Contract NAS8-21012.

1.5 FPE INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

1.5.1 LAUNCH SUPPORT REQUIREMENTS. All equipment of this FPE is completely installed in the spacecraft and does not involve any support during launch operations. The only potential exception is an optional external radiator (see Section 1.5.5) which might be deployed in orbit, either by mechanical means or be EVA assembly.

All equipment is further inactive during launch and requires no operational support, such as power or pressurization. Equipment installation prior to launch includes provisions for the protection of sensitive instrumentation against launch accelerations.

The interface and support requirements disucssed in Sections 1.5.2 through 1.5.8 refer exclusively to orbital operations.

1.5.2 WEIGHT AND VOLUME. The total weight and volume requirements of this FPE for the minimum and the desirable capability levels are:

Minimum	Weight	2,154	kg	(4,750 lb)
	Volume	22.3	m^3	(788 ft^3)
Desirable	Weight	3,672	kg	(8,100 lb)
	Volume	38.2	m^3	(1,350 ft^3)

These total requirements comprise 84 individual equipment units for the minimum, and 124 for the desirable capability level. With regard to their physical interface requirements with the spacecraft, these units may be divided into three groups as follows:

Group I: Large equipment units, with average weights and volumes in the order 80 kg (176 lb) and 0.7 m^3 (25 ft^3), which should be located in one complex. (Units B-01 to B-09 and S-08 in Table 1-2.)

Group II: Large equipment units with an average weight and volume of 130 kg (287 lb) and 1.8 m^3 (63 ft^3), whose location close to Complex I is desirable, but not mandatory; they may be located elsewhere in the spacecraft. (Units B-10 and S-01 to S-07 in Table 1-2.)

Group III: Small interchangeable attachments to Group I units, with an average weight and volume in the order of 10 kg (22 lb) and 0.02 m^3 (0.7 ft^3). The majority of these units are installed in the Group I equipment at any given time, while the remainder are stored in unit S-06 of Group II.

Weight and volume requirements of the three equipment groups are summarized in Table 1-3 for the minimum and the desirable capability level.

Table 1-3. Weight and Volume Requirements

Equipment Group		Minimum Capability			Desirable Capability		
		I	II	III	I	II	III
Number of Units		10	8	66	12	8	104
	Total	84			124		
Weight	Min	15 (33)	12 (269)	1 (2.2)	25 (55)	12 (2691)	1 (2.2)
kg	Max	204 (450)	210 (462)	90 (198)	204 (450)	450 (990)	150 (330)
(lb)	Avg	75 (165)	93 (205)	10 (22)	85 (187)	180 (396)	12 (26.4)
Group Total		754 (1660)	747 (1620)	653 (1440)	1,014 (2230)	1,362 (3000)	1,296 (2585)
	Total	2,154 (4740)			3,672 (8070)		
Volume	Min	0.2 (70.8)	0.25 (88.5)	0.001 (0.354)	0.2 (70.8)	0.25 (88.5)	0.001 (0.254)
m^3	Max	1.5 (530)	8.0 (2850)	0.2 (70.8)	2.2 (780)	15.0 (5300)	0.2 (70.8)
(ft^3)	Avg	0.6 (212)	1.5 (530)	0.015 (5.3)	0.75 (266)	2.2 (780)	0.022 (7.8)
Group	Total	6.3 (2250)	15 (5300)	1.0 (354)	9.05 (3200)	26.9 (9520)	2.25 (795)
	Total	22.3 (7900)			38.2 (13,520)		

The weight figures do not include the coolant weight for the heat rejection system, since there are several options for the mode of heat dissipation which vary substantially in coolant requirements from 500 kg (1,100 lb) for a minimum capability external radiator to 6,000 kg (13,200 lb) for a full-capability storage system. The data for unit S-02 in Table 1-2 likewise accounts only for equipment weight and volume and excludes coolant weight.

Volume requirements are of the same order of magnitude for all rejection systems of the same capability. The external radiator, even though less desirable as a special extravehicular structure, has the advantage that the intravehicular volume fraction of the heat rejection system is comparatively small (approximately 5%).

1.5.3 ACCELERATION LIMITS. For 81% of the MS/MS experiments, the acceleration level must be limited to zero-g $\pm 10^{-3}$ to $\pm 10^{-4}$ g for various lengths of time, 52% for an average period of 2 hours, 27% for periods of 8-20 hours, and 2% for a period of 100 hours. More detailed data on the number of experiments at these two g-levels and various times at each level, are presented in Table 1-4.

For several Class 5 (Physical Processes in Fluids), research experiments, an acceleration limit of zero-g $\pm 10^{-5}$ g will be desirable; this is, however, not designated as a requirement, since these experiments are not yet accurately definable and can, further, be scheduled to coincide with favorable spacecraft acceleration periods.

Table 1-4. Acceleration Limits on MS/MS Experiments

Time (hrs)		Zero-g $\pm 10^{-3}$ g			Zero-g $\pm 10^{-4}$ g		
		No. of Experiments		Experiment	No. of Experiments		Experiment
Range	Avge.	Min.	Des.	Classes	Min.	Des.	Classes
1-4	2	98	240	1A, 1B, 1D, 2B, 2C	74	264	1C, 3A, 3B, 5A
6.5 -12	8	12	26	2A	40	200	4A
4-100	20	20	60	2D	—	—	—

1.5.4 POWER REQUIREMENTS. The power for all MS/MS equipment and operations is supplied through its own Power Conditioning and Distribution Center (Unit B-10) which represents the only interface point between MS/MS power requirements and the spacecraft power system. The MS/MS power conditioning unit is described in Section 1.2.2; it includes a storage battery which supplements all power requirements of the MS/MS FPE in excess of 5 kW.

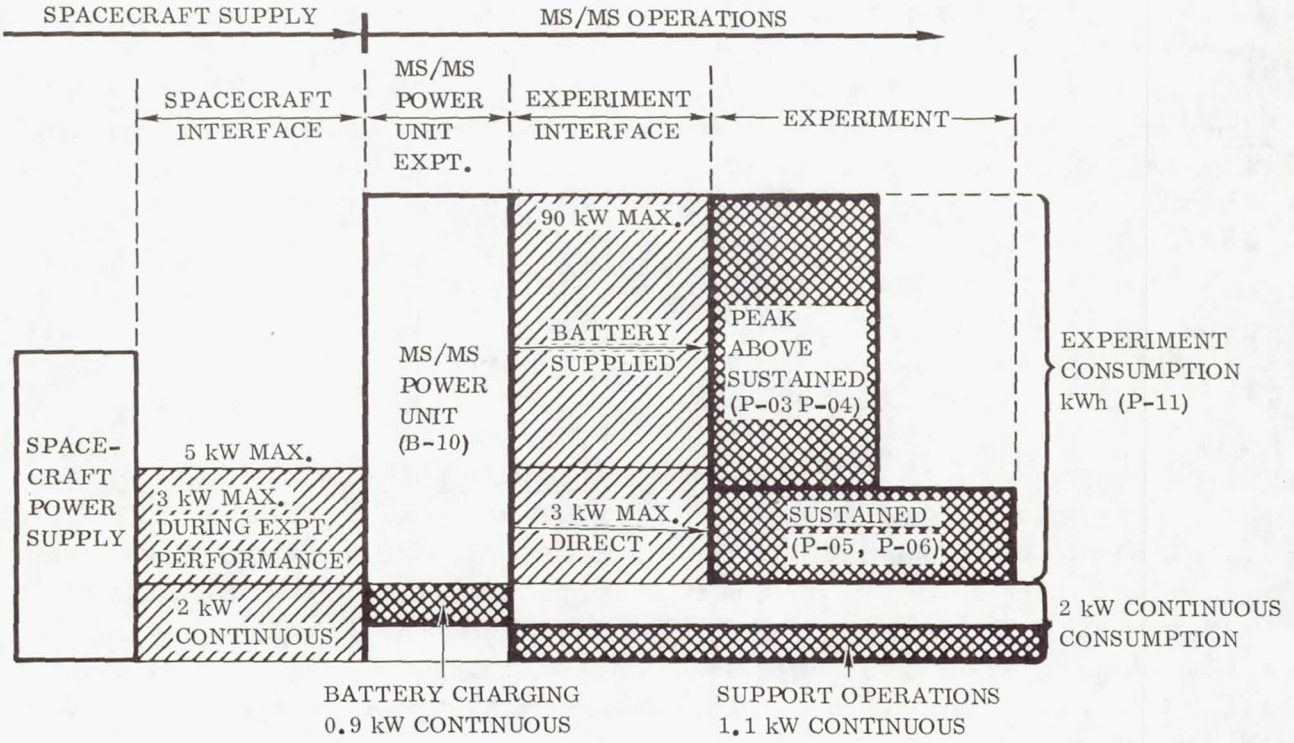
The power supply and consumption interfaces between the spacecraft, the MS/MS power conditioning unit, and individual experiments are illustrated in Figure 1-7. The power interface between the spacecraft busses and the MS/MS power continuous unit consists of a continuous supply of 2 kW which may increase to the maximum level of 5 kW maximum during experiment performance. The power output of the power conditioning unit comprises two groups of consumers:

a. Experiment performance, with peak power levels ranging from 2 to 90 kW and total consumption from 1.2 to 44 kWh.

b. Support operations at a continuous average power level of 1.1 kW.

More detailed data on the total FPE power requirements during experiment performance are presented in Table 1-5. The variety of experiment power profiles is reduced to four typical profiles, illustrated in Figure 1-8, which cover the following fractions of the total experiment program:

Profile I	57%
Profile II	17%
Profile III	20%
Profile IV	6%



REFERENCES IN () IDENTIFY RELATED DESCRIPTORS IN TABLE 1-2

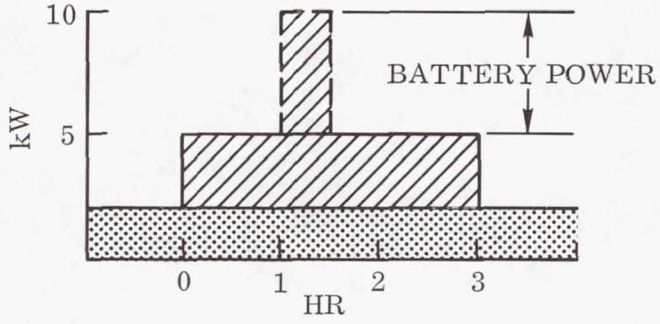
Figure 1-7. MS/MS Power Supply and Consumption

Table 1-5. Data for Typical MS/MS Power Profiles

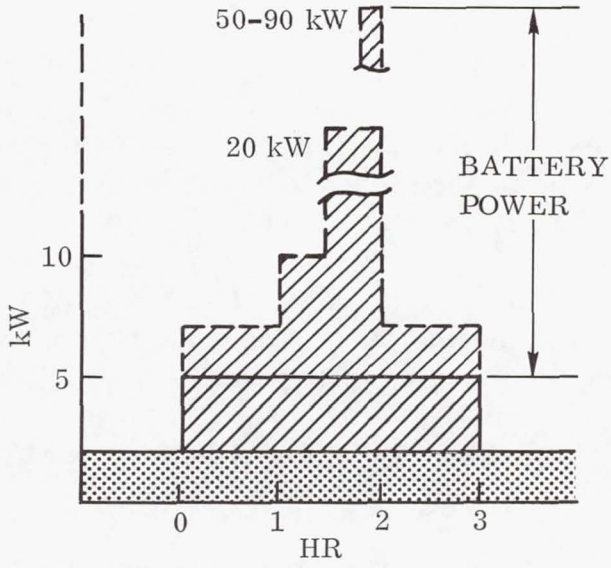
Power Profile	% of Expt. Program	Average Sustained*		Average Peak*		Average Consumption kWh*	Experiment Classes
		kW	hr	kW	hr		
I	57	4.5	2	(9)	0.5	13.5	1A, 1B, 1D, 2B, 2C, 4B, 5A
II	17	(7)	2	(17)	0.35 - - - - - 0.1	22	1C - - - - - - - 3A, 3B
III	20	4	10	(11)	0.4	28	2A, 4A
IV	6	3.5	18	(10.5)	20 × 0.1	84	2D

*Including support operations (equals total MS/MS consumption during experiment performance).

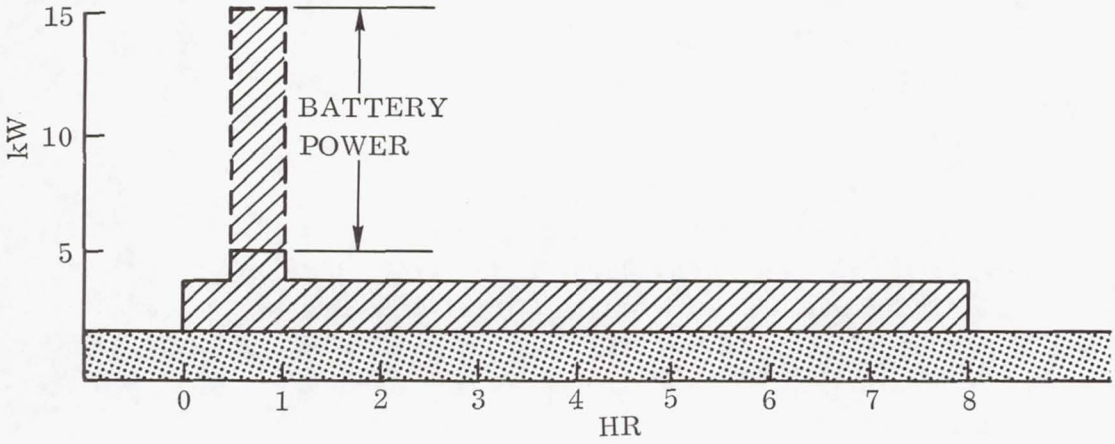
Figures in () = Battery supplement power.



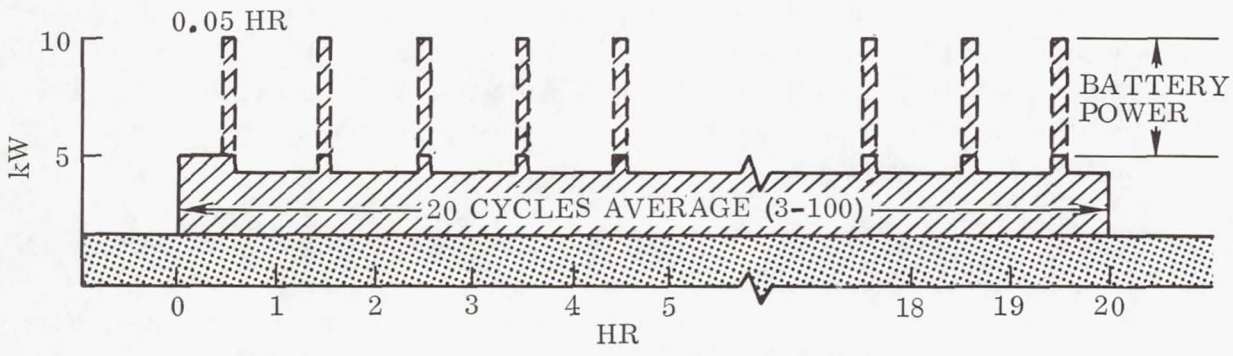
POWER PROFILE I
(57% OF EXPERIMENTS)



POWER PROFILE II
(17% OF EXPERIMENTS)



POWER PROFILE III
(20% OF EXPERIMENTS)



POWER PROFILE IV
(6% OF EXPERIMENTS)

Figure 1-8. Typical Power Profiles for MS/MS Experiments

Specific data on power requirements of each experiment class are included in Block C2 of Table 1-2 (Section 1.2). As indicated in Figure 1-7, these data represent only the consumption listed in "a" above and do not include the 2-kW continuous consumption for battery charging and "b" above.

1.5.5 THERMAL CONTROL REQUIREMENTS. Thermal requirements of MS/MS experiments, other than those of general spacecraft operations (life support, etc.) comprise three categories:

a. Heat required for experiment performance.

b. Heat rejected by experiment apparatus.

c. Heat rejected by MS/MS support equipment.

Since most MS/MS experiments involve the melting of materials, they require substantial amounts of heat. The concerned heat loads per experiment run for each experiment class are identified in line P-12 of Table 1-2 (Block C2). However, since the related heating devices are integral components of the apparatus, the experiment heating interfaces with the spacecraft solely in the form of power requirements which are included in Section 1.5.4.

The thermal interface between MS/MS operations and the spacecraft consists primarily in rejected heat. The heat rejected during the individual experiment "run", (b, above), ranges from 2.09 MJ to 670 MJ (500 to 160,000 kcal), and the rejection rates range from 2.09 to 20.9 MJ/hr (500 to 5000 kcal/hr) over various periods of time. These values include that portion of the 2-kW continuous energy input which is used for battery charging, as it becomes a part of the total energy consumed and transformed into heat during experiment performance.

In Table 1-6 the heat rejection of all MS/MS experiments is represented by five predominant rejection profiles, specifying average rejection rate, during and highest total heat per run, as well as the percentage of experiments pertinent to each profile. The data have been reduced from a variety of rejection rate - time characteristics, all exhibiting a certain hysteresis with regard to the experiment performance cycle. The data are not affected by the magnitude of the experiment program (number of runs per year), except for the frequency of rejection cycles.

Heat rejected by the support equipment, (c), above, varies only slightly over time and ranges from 2.51 to 5.87 MJ/hr (600 to 1400 kcal/hr), with a mean of 3.76 MJ (900 kcal) per hour, extending over 25% of the total stay-time for the minimum program level, and 60% for the desirable level.

Table 1-6. Rejected Heat of MS/MS Experiments

Heat Rejection Profile	Average Heat Rejection Rate MS/hr (kcal/hr)	Duration of Rejection Cycle (hr)		Max. Total Rejected Heat per Cycle MJ (kcal)	% of Experiment Program	Experiment Classes
		Range	Mean			
I	3.35 (800)	1-5	4	18 (4,300)	34	4B, 5A
II	5.87 (1,400)	5-10	7	57.5 (13,700)	36	1A, 1B, 1D, 2A, 4A
III	7.55 (1,800)	7-100	22	670 (160,000)	6	2D
IV	10.49 (2,500)	3-5	4	50.4 (12,000)	18	1C, 2B, 2C
V	18.85 (4,500)	3-5	4	92.3 (22,000)	6	3A, 3B

It is expected that the category "c" heat (support equipment) can be absorbed by the spacecraft thermal control system. To what degree this mode can also be applied to category "b" depends on the spacecraft design and the overall thermal requirements. It is apparent that the higher rejection rates of 8.38 to 20.95 MJ/hr (2000-5000 kcal/hr) necessitate a special heat dissipation system, such as a coolant storage device for gradual heat dissipation, or an external radiator. Reasonable provisions for such a system are included in the MS/MS equipment specification (Unit S-02, Table 1-2). For weight and volume requirements of the heat rejection system, see Section 1.5.2.

1.5.6 DIGITAL DATA AND COMMUNICATIONS. MS/MS experiments call for three types of transmission support:

a. Digital data transmission and storage.

b. Direct TV and voice transmission.

c. TV and voice storage for replay to ground station.

The total yearly time of digital data transmission at a predominant rate of 10^4 bps is as follows:

Minimum Program	1,370 hours/year
Desirable Program	4,700 hours/year

The total yearly time of TV and voice transmission at a rate of 10^7 bps is:

Minimum Program

Direct	260 hours/year
Stored/Replay	842 hours/year

Desirable Program

Direct	1,076 hours/year
Stored/Replay	3,708 hours/year

Replay of TV/voice to the ground may be selective and comprise only a part of the total stored transmission. More detailed data on transmission requirements of individual experiment classes are listed in Block C of Table 1-2.

1.5.7 LOGISTICS SUPPORT REQUIREMENTS. All MS/MS experiments require a periodic supply of experimental materials and equipment-refurbishment components, as well as a periodic return of processed materials to the ground for detailed evaluation. In Shuttle-sortie mission experiments this presents no special logistics requirement, as the experimental materials are deployed and returned with the experiment equipment. For longer orbital stay times, as in a Space Station, periodic logistics support is mandatory. In this case, the logistics requirements in terms of weight and volume per year (per month in parentheses) are:

Up	Minimum	Desirable
Weight, kg	898 (75)	3290 (274)
Volume, m^3	0.39 (0.032)	1.57 (0.130)

Down	Minimum	Desirable
Weight, kg	470 (39)	1,850 (154)
Volume, m^3	0.16 (0.014)	0.6 (0.050)

A fraction of the deployed ("up") material emerges as waste, either in the form of experimental materials waste, or equipment components to be refurbished. As long as the mode of waste disposal in space is not resolved, the potential necessity of the return of all waste materials has to be contemplated. In such case, the following return weights and volumes apply:

Down	Minimum	Desirable
Weight, kg	898 (75)	3,290 (274)
Volume, m^3	0.42 (0.035)	1.66 (0.138)

More detailed data on logistics weights and volumes are presented in Table 1-7.

Table 1-7. Logistics Weights and Volumes

Logistics	Materials	Per Year Minimum	Per Year Desired	Per Month Minimum	Per Month Desired
Up	Weight, kg				
	Experiment Materials	706 (1553)	2,810 (6180)	59 (130)	234 (515)
	Refurbishment Materials	192 (420)	480 (1056)	16 (35.2)	40 (88)
	Total Weight Up	898 (1975)	3,290 (7240)	75 (165)	274 (604)
	Volume, m^3				
	Experiment Materials	0.326 (45.5)	1.407 (498)	0.027 (9.55)	0.117 (41.5)
	Refurbishment Materials	0.064 (22.65)	0.160 (56.6)	0.005 (1.77)	0.013 (4.6)
	Total Volume Up	0.390 (138)	1.567 (550)	0.032 (11.32)	0.130 (46)
Down	Weight, kg (lb)				
	Experiment Products	470 (1034)	1,850 (4070)	39 (85.6)	154 (339)
	Experiment Waste Material	236 (519)	960 (2112)	20 (44)	80 (176)
	Refurbished Waste Material	192 (420)	480 (1056)	16 (35.2)	40 (88)
	Total Weight Down	898 (1975)	3,290 (7240)	75 (165)	274 (603)
	Volume, m^3				
	Experiment Products	0.163 (57.7)	0.604 (214)	0.014 (4.95)	0.050 (17.7)
	Experiment Waste Material	0.196 (69.4)	0.899 (318)	0.016 (5.66)	0.075 (26.6)
	Refurbished Waste	0.064 (22.6)	0.160 (56.6)	0.005 (1.77)	0.013 (4.61)
	Total Volume Down	0.423 (149.5)	1.663 (588)	0.035 (12.4)	0.138 (48.9)

1.5.8 CREW SUPPORT REQUIREMENTS. The skills required for each experiment class are identified in Block B of Table 1-2. The combined manhours per year for all skills and the entire program are as follows:

Minimum Program	2,266 manhours/year
Desirable Program	5,991 manhours/year

The average manhours per experiment "run" are 8 hours for the minimum program, 6 hours for the desirable program.

The manhour breakdown according to experiment classes, which may be of significance for partial programs or Shuttle-sortie missions, is defined in Table 1-8. The type of activities to be carried out by each skill are defined in Section 1.7.

1.5.9 INTERFACE REQUIREMENTS SUMMARY. The most significant interface requirements data are summarized in Table 1-9. These data represent, in the best judgement of NASA scientists, the overall facility and experimental requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight and experiment definition and integration programs.

Table 1-8. Crew Time Requirements

Experiment Class	Manhours Per Year		Average Manhours Per Run
	Minimum	Desired	
1A	240	600	10
1B	160	400	10
1C	192	600	12
1D	108	252	9
2A	144	312	12
2B	338	792	13
2C	220	440	11
2D	240	720	12
3A	156	420	11
3B	72	284	12
4A	160	500	3
4B	60	200	1
5A	200	525	4
Total	2,290	6,047	7

Table 1-9. MS/MS Interface Requirements Summary

Weight	Minimum Capability:	2,154 kg	(4,750 lb)
	Desirable Capability:	3,672 kg	(8,100 lb)
Volume	Minimum Capability:	22.3 m^3	(788 ft^3)
	Desirable Capability:	38.2 m^3	(1,350 ft^3)
Power	Maximum Sustained:	2 kW	(Desirable Minimum)
	Peak (< 0.5 hr):	5 kW	
Data Rate	Maximum - All Data:	10^5 bps	
	TV - Voice:	10^7 bps	
Logistics Up	Minimum Capability:	75 kg/mo	(165 lb/mo)
	Desirable Capability:	274 kg/mo	(605 lb/mo)
Logistics Down (Products)	Minimum Capability:	39 kg/mo	(86 lb/mo)
	Desirable Capability:	154 kg/mo	(340 lb/mo)
Logistics Down (Incl. Waste)	(Same as up)		
Pointing and Stability	N/A		
Orbital Altitude and Inclination	N/A		
Acceleration Limit	Minimum Capability:	Zero-g $\pm 10^{-4}$ g	
	Desirable Capability:	Zero-g $\pm 10^{-5}$ g	

1.6 POTENTIAL MODE OF OPERATION

All MS/MS experiments are essentially independent of vehicle mechanics except for the requirement of sustained low g-levels during the processing cycle which, in most cases, is only in the order of 1 to 8 hours, with a few experiments extending up to 100 hours. However, the experiment schedule can be accommodated without any difficulty in predictable vehicle maneuvering periods.

Since the MS/MS FPE is a self-contained facility, it does not interfere with vehicle or other experiment operations, except for the interface requirements defined in Section 1.5. The experiment program and the related equipment and operational requirements are, however, affected by the mode of payload deployment and on-orbit stay-time as follows:

a. Limited On-Orbit Stay-Time. Limited stay-time refers primarily to MS/MS payload and experiment performance onboard the Space Shuttle. Each mission will comprise a limited set of experiments selected for highest commonality in equipment and performance requirements as they can be derived from Table 1-2. While the apparatus units apply as defined in the table, some supporting basic units, such as the Instrumentation and Control Center or the Power Conditioning System (units B-08 and B-10) will be used in a scaled-down version, which is facilitated by their modular design; support units will be limited to those necessary for experiment performance, and exclude evaluation equipment or storage facilities except for the special storage equipment for biological experiments. Skills will be limited as much as possible to "principal functions" as defined in Table 1-2 and Section 1.7. All experiment materials will be included in, and returned with, the MS/MS facility.

b. Extended On-Orbit Stay-Time, Periodically Revisited by Shuttle. While the mode of deployment is optional and may employ either the Space Shuttle or any other launch vehicle, revisiting will be exclusively accomplished by the Space Shuttle. As in Mode A, each mission will comprise a limited set of experiments. The more extensive stay-time permits the performance of a greater number of experiments and will require more extensive support equipment as well as some skills in a "supporting function," as defined in Table 1-2 and Section 1.7. The prime function of the revisiting missions consists of the supply and return of experimental materials and the exchange of personnel, if indicated.

c. Extended On-Orbit Stay-Time for the Space Station. The capabilities of the Space Station are utilized most efficiently by the deployment of the complete MS/MS FPE as described in Section 1.2. Limitations of the experiment program have essentially no effect upon the total facility weight and volume, as the omission of specific experiment classes represents but little weight and volume. Likewise, the performance, interface and skill requirements will not differ significantly

from the data in Table 1-2 and the specifications in Sections 1.5 and 1.7. A mandatory requirement is a periodic revisiting for the supply of experimental and equipment-refurbishment materials, as well as for the return of experiment products and waste materials.

1.7 ROLE OF MAN

The astronaut/worker performs several functions in the implementation and accomplishment of an ongoing Materials Science and Manufacturing in Space experimental program. Primary roles consist of equipment setup, experiment performance and experiment evaluation.

Results and products of the experiments will be evaluated and communicated to Earth. In advanced stages, consistent with practiced engineering and scientific skills, critical value judgments may be made by the astronaut to modify the processes or experiments. In all cases, the astronaut is essential in utilizing the capabilities of a laboratory containing a complex of multipurpose equipment and ancillary support items. Only with man as a key element can a multiexperiment program be effected within the R&D time frame. It is anticipated that variable work plans and astronaut roles will be associated with a maturing experimental program as space experience in this area is developed.

Crew activities comprise two major functional categories: activities associated with equipment operation and those associated with experiment performance. Equipment operation includes apparatus setup, reconfiguration, refurbishment, and maintenance, as well as instrument calibration. Experiment performance consists of experiment (run) scheduling, definition of apparatus configuration and experiment conditions, monitoring of experiment performance, and evaluation of experiment results.

The required individual skills, their major functions and their role in the experiment performance (principal or supporting function) are as follows:

a. Biological Technician (Skill 1). Preparation and performance of Group 4 experiments (principal function).

b. Biochemist (Skill 3). Performance of confirmatory assays and tests on products of Group 4 experiments (supporting function).

c. Physicist (Skill 6). Occasional assistance in the preparation and evaluation of Experiment Groups 1, 2, 3 and 5 (supporting function). Occasionally, assumes principal function in the performance of selected Group 5 experiments.

d. Photographic Technician (Skill 8). Assists in the installation of motion picture and TV cameras. Operates the Photographic Processing Laboratory (Unit S-05); processes motion picture films and still pictures, such as photomicrographs or x-ray diffractograms (supporting function).

e. Electronic Engineer (Skill 10). Directs installation and operation of electronic measuring and recording systems, as well as data, TV and voice transmission equipment (supporting function).

f. Electromechanical Technician (Skill 12). Performs all apparatus assembly and maintenance operations, such as installation of mechanical and electrical equipment units, or equipment repair and refurbishment; maintains materials and fluids storage facilities (principal function).

g. Optical Technician (Skill 14). Installs and checks out optical instrumentation and measuring devices (supporting function).

h. Optical Scientist (Skill 15). Occasionally advises in the set-up of optical instrumentation; performs preliminary evaluation of glasses produced in Group 3 experiments (supporting function).

i. Metallurgist (Skill 23). Schedules, prepares, performs and evaluates all Group 1 and most Group 2 experiments (principal function). Skill requires thorough knowledge in all phases of general metallurgy, including the testing and analysis of metals, and special experience in the behavior of metals in the liquid state and during solidification.

j. Materials Scientist (Skill 24). Schedules, prepares, performs and evaluates experiments of Groups 2, 3 and 5; advises in the performance of other experiment groups and in the interpretation of experiment results (principal function). Skill requires familiarity with all phases of materials sciences, such as the physics of solids and fluids, or the fundamentals of metallic and nonmetallic materials.

k. Physical Chemist (Skill 25). Assists in the preparation, performance and evaluation of all experiment groups (supporting function). Skill requires broad experience in physics and chemistry, and special knowledge in transport phenomena in fluids and fluid/solid interfaces.

1.8 SCHEDULES

The minimum lead times to flight or deployment capability for each experiment class are defined in Figure 1-9. The lead times are composed of: 1) the time required for R&D on processes, related fundamentals, processing techniques, and equipment development; 2) hardware development, manufacturing, and checkout. This schedule is exclusively based on technical considerations and does not account for vehicle schedules and availability.

The approach or framework in which the Materials Science and Manufacturing in Space FPE will be implemented is depicted by Figure 1-10, where the program is categorized in six major areas of activity. Although each of these major areas of activity can be identified separately, they are functionally very closely related.

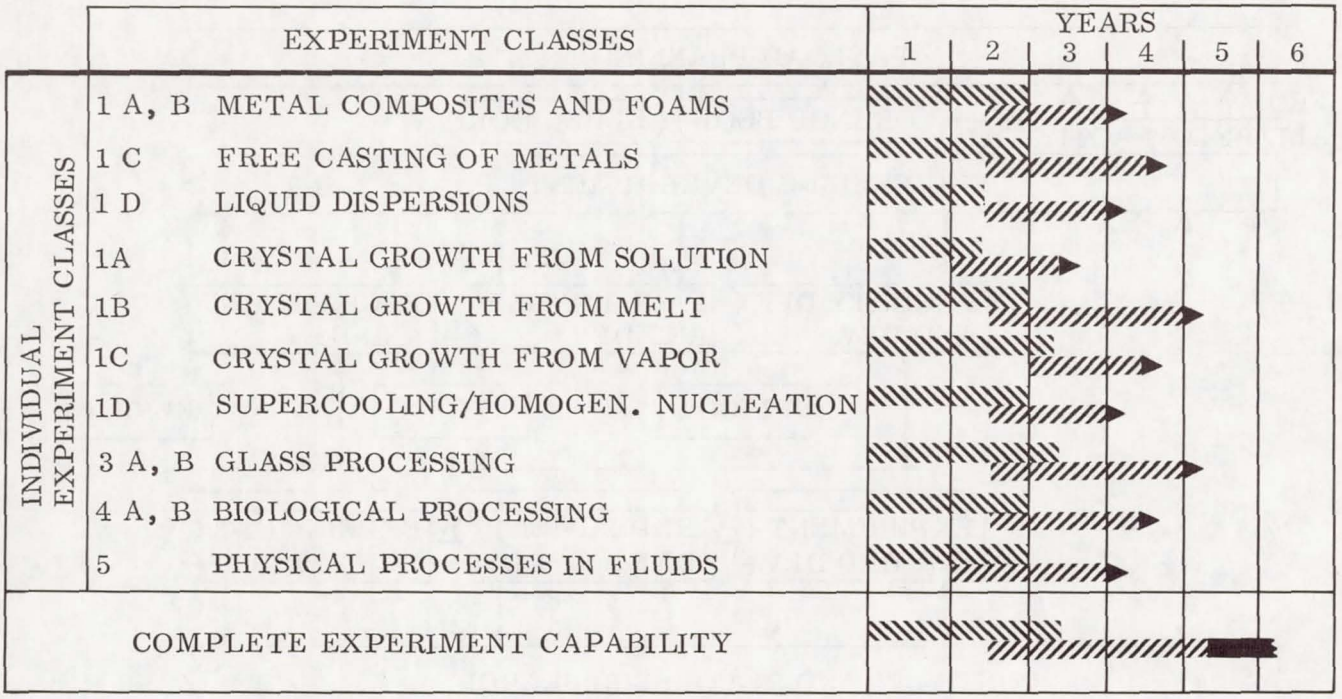


Figure 1-9. Experiment Development Schedule

User Relations embraces those activities in which NASA interfaces with representatives of the potential user community in order to stimulate new ideas and proposals through the cross-fertilization of ideas, to develop a close working relationship and to give the program publicity. In essence, User Relations is the public relations portion of the program. Examples of activities coming under this category which have occurred to date are the MSFC Symposia and the Carnegie-Mellon University Study.

Contract and In-House Research embraces those ground-based activities (including paper studies, laboratory research, drop-tower testing, demonstration testing, etc.) aimed at determining the space environment effect on the basic mechanisms of various processes and to determine the feasibility of using the unique characteristics of the space environment to satisfy the needs and requirements proposed by potential users. In essence, the contract and in-house research activities develop the warehouse of knowledge and technology from which the ideas to perform specific space experiments or research evolve. Examples of activities in this category that have been conducted to date include studies on crystal growth, electrophoresis, and composite castings.

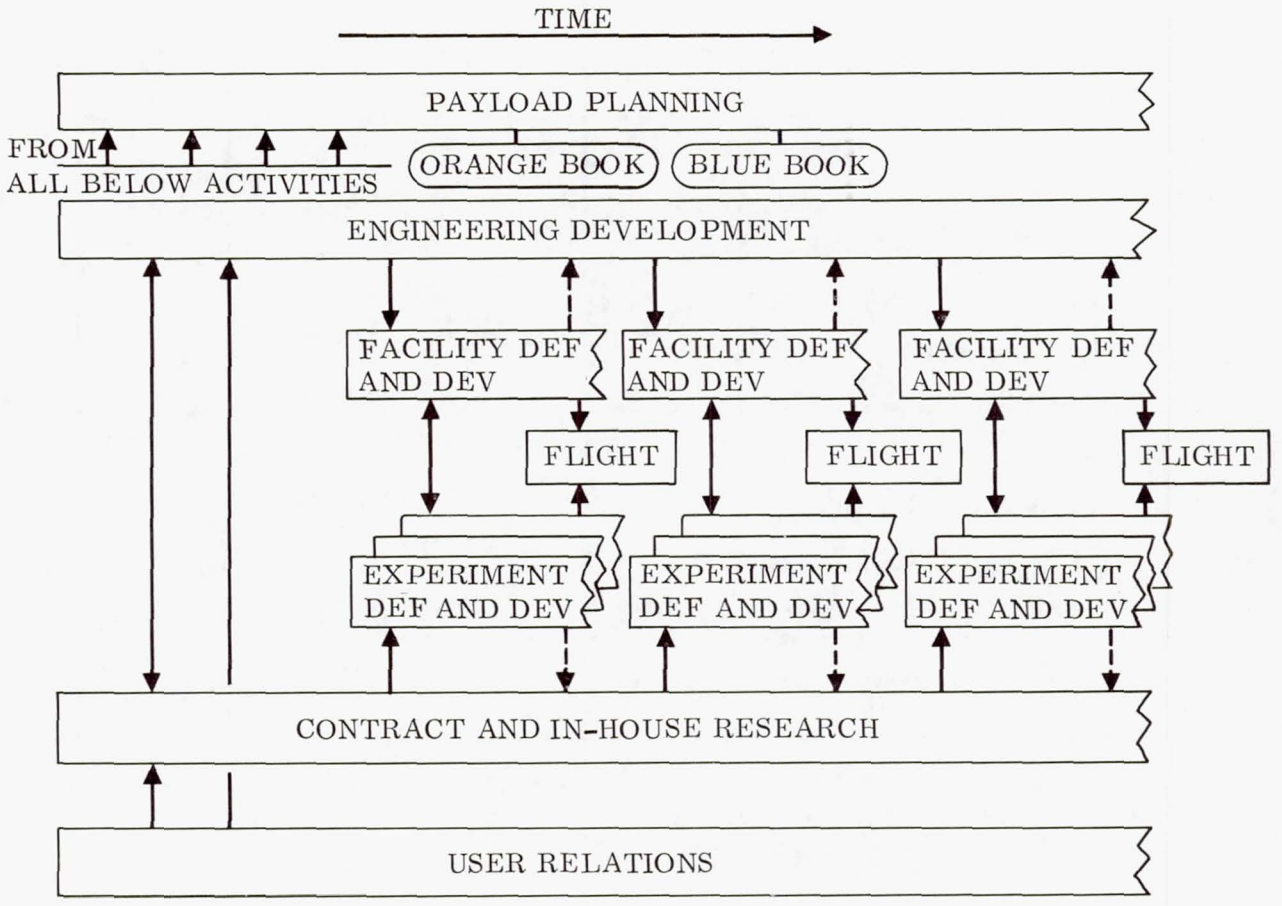


Figure 1-10. MS/MS Development Relationships

Engineering Development includes those ground-based activities (including paper studies, laboratory research, drop-tower testing, demonstration models, etc.) aimed at identifying the preferred equipment, instrumentation, etc., that will be required to conduct user-requested in-space experiments and research. The engineering development activities provide the knowledge and technology upon which the proposed flight facilities are based. Typical activities in this area are the study and definition of material positioning and handling devices, heating devices, instrumentation equipment, analytic equipment, etc. In many cases, specific items of equipment such as furnaces and positioning devices may be well into Phase A and in a few cases into Phase B definition while still being handled under the engineering development category.

Experiment Definition and Development includes all activities from Phase A through Phase D for specific in-space experiments. Generally speaking, the pre-Phase A work for a specific experiment is expected to have been accomplished within the contract and in-house research activity. Also, generally speaking, a specific experiment will not begin a formal Phase B until after a specific flight opportunity has been identified and an AFO has been released. At this point in time, the only activities going on in this area are the six experiments for Skylab B and some current work to identify potential Apollo flyback experiments.

Facility Definition and Development embraces Phase A through Phase D for specific in-space Materials Science and Manufacturing facilities associated with specific flight opportunities such as Skylab B, Space Station or Shuttle. Generally speaking, the majority of the pre-Phase A work for the individual equipment items (such as furnaces, positioning devices, and analytical equipment) will have been accomplished within the area of engineering development. At this point in time, the only activity going on in this area is the development of M512 for flight with Skylab A.

Payload Planning is that activity wherein, on a continuous basis, Typical Candidate Facilities and Experiments are identified, documented, and provided to organizations reponsible for carrying out overall manned space flight planning and definition work such as the Phase B Space Studies, Shuttle Studies, Skylab B studies, etc.

The functional relationship between these major activity areas is depicted in Figure 1-9. The general flow is that User Relations gives rise to ideas for potential space products. Contract and In-House Research and Engineering Development work proceed, and lead to the delivery of flight facilities and experiments.

Representative schedules are shown in Figures 1-11 and 1-12. Figure 1-11 is representative of the case where the MS/MS facility is accommodated by the Space Station - Experiment Module. Figure 1-12 represents the case in which the Space Shuttle (Sortie Mission) would accommodate the MS/MS Facility. As can be seen in the Space Station - Experiment Module case, the Facility Definition effort and the Experiment Definition efforts will be conducted in parallel with cross-coupling to ensure that the experiment will fit the facilities and the facilities can implement the experiments. During design and development work, the experiment will be constrained to stay within the facility capabilities. The Space Shuttle (Sortie Mission) schedule is very similar in approach to the Space Station - Experiment Module since an Experiment Module can be used in both cases. The Shuttle-sortie mission accommodates experiment payloads in an internal experiment module which is reconfigured between flights.

As shown by Figures 1-11 and 1-12, Phase A and to some extent Phase B vehicle studies can rely on the "Blue Book" to provide payloads which will drive conceptual vehicle design. However, the output of the facility definition and development effort must be available before the vehicle design proceeds into Phase C in order to avoid costly redesign.

1.9 PRELAUNCH SUPPORT AND GSE

MS/MS experiment modules for both Space Station and Space Shuttle are delivered to the launch complex as self-contained units with provisions for the protection of instrumentation against launch acceleration. They require no special support during the prelaunch or launch period. This applies equally to the periodic resupply of materials.

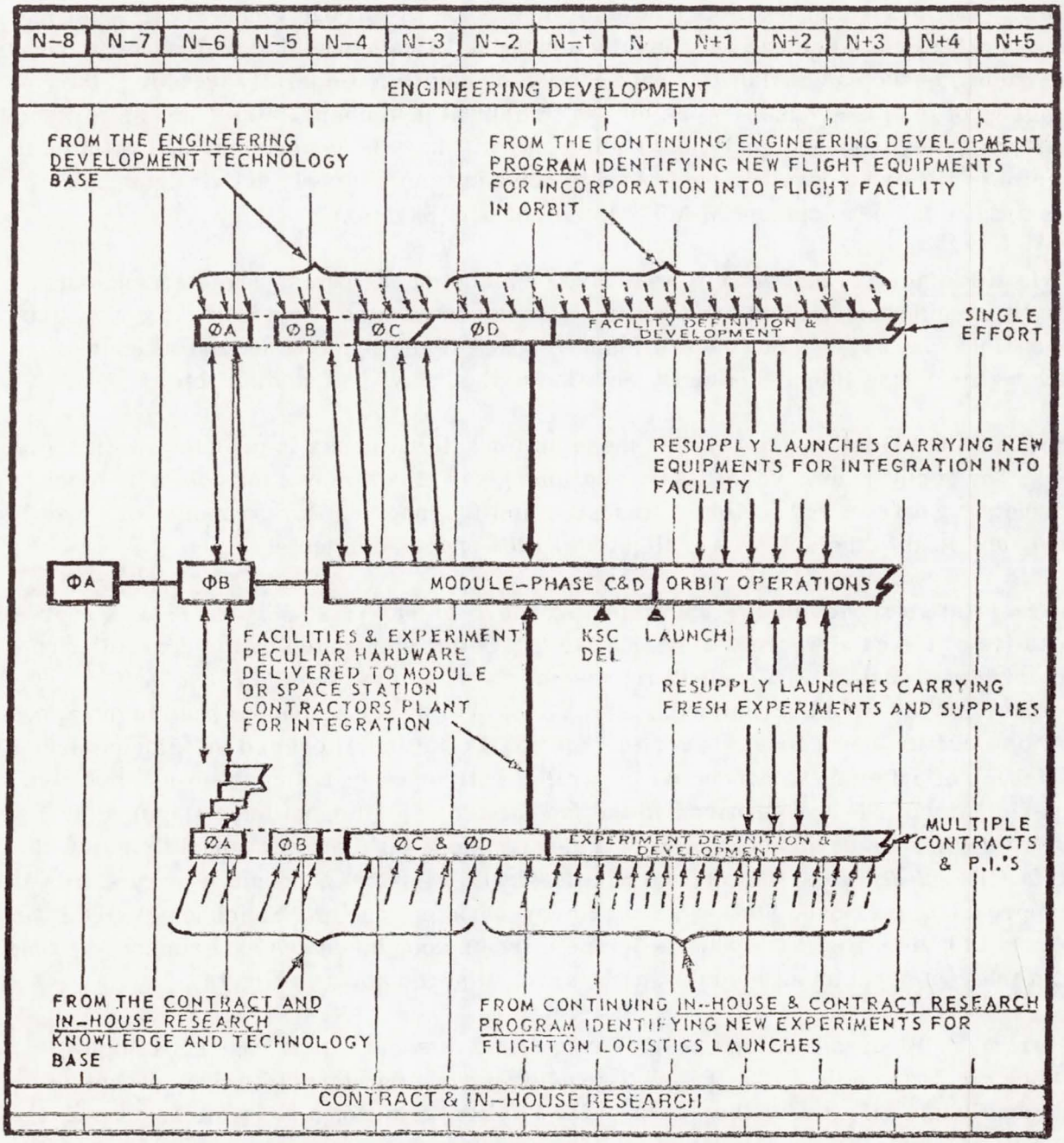


Figure 1-11. Representative Schedule for MS/MS Experiment Module (Space Station)

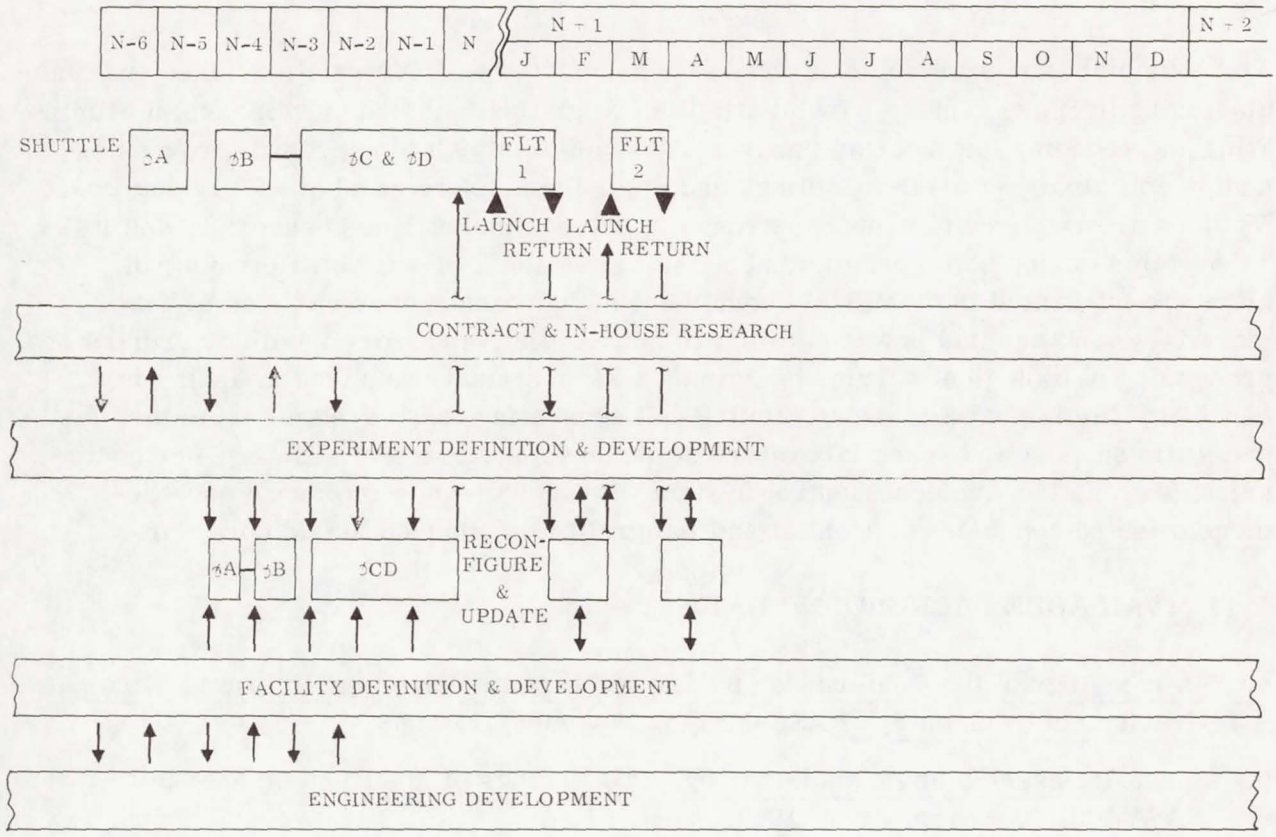


Figure 1-12. Representative Schedule for Space Shuttle-Accommodated MS/MS Experiments

The only exception are some perishable sample materials for biological processing (Classes 4A, 4B) which will require refrigeration during the prelaunch and launch periods; some selected biological materials will have to be loaded shortly before launching.

For the return of processed materials and not-otherwise-disposable waste materials from a Space Station module, provisions have to be made for accommodation of the weights and volumes defined in Section 1.5.7 in the return vehicle. In the case of limited on-orbit stay-time, experiment and waste materials are returned with the equipment module.

Ground support equipment for experiment operations consists primarily of communications facilities for direct TV and voice transmission and for replay of stored data, TV and voice.

1.10 SAFETY ANALYSIS

The equipment and experimental programs associated with Materials Science and Manufacturing in Space require careful attention be given to methods and means of eliminating and reducing the inherent hazards attendant with high temperature processing equipment, toxic materials handling, and other forms of releasable energy sources. Methods are required to protect astronauts, the equipment, the spacecraft, and its subsystems during both normal or abnormal situations. Positive safety control elements integrated in the MS/MS equipment include emergency methods of hot materials containment, power cutoff, pressure relief, and fire control. Furthermore, processing of biological serums containing toxic materials requires an isolation capability (Biological Enclosure, Unit B-05) separating those systems from the primary life support and space laboratory shirtsleeve environment. Emergency equipment, such as the Accident Control System (Unit S-08), and preplanned countermeasures are considered essential and integral to the planned MS/MS program.

1.11 AVAILABLE BACKGROUND DATA

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TABLE 1-2. MS/MS EXPERIMENT REQUIREMENTS SUMMARY

(COMMON UNITS)

A

1		2													3																	
REQUIREMENTS		EXPERIMENT CLASSES													EQUIPMENT DATA																	
EQUIPMENT UNITS		1 METALLURGICAL				2 CRYSTAL GROWTH				3 GLASSES		4 BIOLOG.		5 PHYS.	MINIMUM CAPABILITY									DESIRABLE CAPABILITY								
		1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4A	4B	5A	QTY. EACH	DIMENSIONS (ft) X	Y	Z	WT. (lb)	VOL. (ft3)	POWER (kw) MAX.	SUST.	DIG. DATA BPS	QTY. EACH	DIMENSIONS (ft) X	Y	Z	WT. (lb)	VOL. (ft3)	POWER (kw) MAX.	SUST.	DIG. DATA BPS
BASIC UNITS	B-01 CONTROLLED ATMOSPHERE CHAMBER			●			○	○	●					○	1	6.56	2.62	2.62	330	31.8	1.0	0.1	10^1	1	7.88	3.28	3.28	463	60	1.0	0.1	10^1
	B-02 ENVIRONMENTAL CHAMBER 'A' – PASSIVE COOLING	●	●	●	●	○	●			○	○				1	3.61	2.3	2.3	132	17.65	1.0	0.2	10^1	1	4.6	2.95	2.95	264	38.9	1.0	0.4	10^2
	B-03 ENVIRONMENTAL CHAMBER 'B' – PASSIVE COOLING	●	●	●	●	●	●	●	●					●	1	2.62	1.64	1.64	66	7.06	0.5	0.1	10^1	2	2.62	1.64	1.64	66	7.06	0.5	0.1	10^1
	B-04 ENVIRONMENTAL CHAMBER 'C' – ACTIVE COOLING	○	○	●	○		○	○	○	●	●			○	1	2.62	1.64	1.64	99	7.06	0.7	0.2	10^2	1	2.62	1.64	1.64	99	7.06	0.7	0.2	10^2
	B-05 BIOLOGICAL ENCLOSURE											●	●		1	4.92	2.95	3.94	448	53	2.1	1.8	10^2	1	4.92	2.95	3.94	448	53	2.1	1.8	10^2
	B-06 LIQUID METAL SUPPLY SYSTEM	●	●	●	○										1	1.31	0.99	0.82	33	1.77	0.8	0.3	10^2	2	1.64	1.31	1.31	55	3.53	1.5	0.5	10^2
	B-07 GENERAL PURPOSE LABORATORY INSTALLATION	○	●		○	●	○	○				●		●	1	3.94	4.92	1.97	88	35.3	1.5	0.3	10^3	1	5.25	4.92	1.97	110	42.5	1.5	0.3	10^3
	B-08 INSTRUMENTATION AND CONTROL CENTER	●	●	●	●	●	●	●	●	●	●	●	●	○	1	4.92	3.28	3.28	264	53	0.5	0.3	10^4	1	4.92	4.92	3.28	320	77.9	0.7	0.3	10^5
	B-09 ATMOSPHERE SUPPLY & CONTROL SYSTEM	●	●	●	○	○	●	○	●	●	●			●	1	2.3	1.97	1.31	154	7.06	1	0.3	10^2	1	3.28	1.97	0.16	220	10.6	1	0.3	10^2
	B-10 POWER CONDITIONING & DISTRIBUTION SYSTEM	●	●	●	●	●	●	●	●	●	●	●	●	●	1	3.28	1.64	1.64	462	8.85	14(50)	9	10^2	1	3.94	1.97	1.64	836	12.4	21(90)	12	10^2
	TOTAL REQUIREMENTS – BASIC UNITS														10				2080	222	23.1	12.6		12				3040	323	33	16.6	
INTERNAL UNITS	I-01 RESISTANCE HEATED FURNACE – 1600°C	●	●	●	●	●		●						○	2	1.31	0.66	0.66	22	0.71	4	1.2	10^1	2	1.64	0.99	0.99	39.6	1.41	6	2	10^1
	I-02 FURNACE – 2600°C – INERT/VACUUM			●	○			○		○	○				1	1.31	0.66	0.66	39.6	0.71	7	3	10^1	1	1.64	0.99	0.99	66	1.41	9	4	10^1
	I-03 FURNACE – 3200°C – OXYGEN									●	●				1	0.99	0.99	0.99	57.2	0.71	9(50)	6	10^2	1	1.31	1.31	1.31	99	1.77	14(90)	8	10^2
	I-04 HEATING AND POSITIONING COILS (SETS)			●			○		○	●	●				3	0.66	0.66	0.66	26.4	0.35	6(15)	2	10^2	5	0.99	0.99	0.99	44	1.41	10(30)	4	10^2
	I-05 PLASMA ELECTRON BEAM UNIT			●						●	●				1	0.66	0.33	0.33	8.8	0.07	5	2	10^1	1	0.66	0.33	0.33	8.8	0.07	–	2	10^1
	I-06 MOLD INJECTION SYSTEM	●	●		●										1	0.33	0.33	0.33	6.6	0.04	–	–	10^1	1	0.49	0.49	0.49	13.2	0.14	–	–	10^1
	I-07 DISPERSION CONTROL SYSTEM	●	●	○	●									○	1	0.82	0.82	0.82	11	0.71	–	–	10^1	1	1.31	1.31	1.31	33	2.47	1	1	10^2
	I-08 LIQUID SPHERE DEPLOYMENT SYSTEM			●											1	0.33	0.33	0.33	6.6	0.04	0.1	–	10^1	2	0.33	0.49	0.49	8.8	0.07	0.1	–	10^1
	I-09 HOLLOW BODIES DEPLOYMENT SYSTEM			●											1	0.66	0.33	0.33	8.8	0.07	0.2	–	10^1	1	0.66	0.49	0.49	13.2	0.14	0.2	–	10^1
	I-10 MEMBRANE DRAWING TOOL			●											1	0.99	0.66	0.33	8.8	0.21	0.1	0.1	10^1	2	1.64	0.66	0.66	15.4	0.71	0.2	0.2	10^1
	I-11 ZONE MELTER						●								1	0.99	0.49	0.49	17.6	0.25	0.2	0.1	10^2	1	1.64	0.49	0.49	19.8	0.35	0.2	0.1	10^2
	I-12 CZOCHRALSKI CRYSTAL PULLER						●								1	1.64	0.66	0.66	26.4	0.71	0.2	0.1	10^2	2	1.64	0.66	0.66	26.4	0.71	0.2	0.1	10^2
	I-13 SUSCEPTOR FOR SILICATE MELTS					●									1	0.33	0.16	0.16	2.2	0.04	0.2	0.1	10^2	2	0.66	0.33	0.33	4.4	0.07	0.2	0.1	10^2
	I-14 HIGH TEMPERATURE CALORIMETER								●						1	0.66	0.33	0.33	15.4	0.07	2	0.5	10^3	1	0.66	0.33	0.33	15.4	0.07	2	0.5	10^3
	I-15 SEED INJECTOR					●									2	0.33	0.10	0.10	2.2	0.004	0.05	0.05	10^1	2	0.33	0.10	0.10	2.2	0.004	0.05	0.05	10^1
	I-16 INTERNAL FRICTION MEASURING DEVICE								●						1	0.33	0.16	0.16	8.8	0.004	0.1	0.1	10^3	1	0.33	0.16	0.16	8.8	0.004	0.1	0.1	10^3
	I-17 STATIONARY ELECTROPHORETIC COLUMN											●			2	0.99	0.99	0.07	22	0.07	0.2	0.02	10^2	4	0.99	0.99	0.07	22	0.07	0.2	0.02	10^2
	I-18 CONTINUOUS ELECTROPHORETIC COLUMN											●			2	0.99	1.47	0.66	44	1.06	0.4	0.09	10^2	4	0.99	1.37	0.66	44	1.06	0.4	0.09	10^2
	I-19 BUFFER RECOVERY/WASTE DISPOSAL SYSTEM											●			2	1.64	0.10	0.10	44	1.77	1	0.2	10^1	4	1.64	0.99	0.99	44	1.77	1	0.2	10^1
	I-20 GAS ELIMINATION/COOLING SYSTEM											●			2	1.64	0.66	0.66	22	0.71	0.5	0.5	10^1	4	1.64	0.66	0.66	22	0.71	0.5	0.5	10^1
	I-21 LYPHOLIZATION APPARATUS												●		1	0.82	0.66	0.66	22	0.35	0.4	0.4	10^1	2	0.76	0.66	0.66	22	0.35	0.4	0.4	10^1
	I-22 MOLDS, CAVITIES, CRUCIBLES (SETS)	●	●		●	●		○						●	5	0.99	0.99	0.66	11	0.71	–	–	–	10	1.64	0.99	0.66	15.4	1.06	–	–	–
	I-23 MISCELLANEOUS INTERNAL ATTACHMENTS (SETS)	●	●	●	○	○	●	○	○	○	○				4	0.66	0.66	0.66	11	0.35	–	–	–	5	0.99	0.66	0.66	22	0.71	–	–	–
	TOTAL REQUIREMENTS – INTERNAL UNITS														38				733	18.6	54.8	22.52		59				1640	48.6	99.2	44.64	
EXTERNAL UNITS	E-01 CONTINUOUS ATMOSPHERE ANALYSIS APPARATUS		•	○			○		●	●	●				1	2.46	1.64	1.64	198	7.06	0.15	0.15	10^3	1	2.46	1.64	1.64	198	7.06	0.15	0.15	10^3
	E-02 HIGH TEMPERATURE VIEWING DEVICE			○			○		○	●	●				1	1.64	0.66	0.66	11	0.71	0.1	0.1	10^2	1	1.64	0.66	0.66	11	0.71	0.1	0.1	10^2
	E-03 CHILL SYSTEM	○	○	○	●										1	1.31	0.66	0.66	13.2	0.71	0.1	–	–	1	1.97	0.99	0.99	22	2.12	0.1	–	–
	E-04 MOTION PICTURE CAMERA			●		○	●	●						●	2	0.99	0.66	0.33	17.6	0.21	0.5	0.5	10^1	3	0.99	0.66	0.33	17.6	0.21	0.5	0.5	10^1
	E-05 TV CAMERA		○	●		○	●	●	○			●		●	3	0.66	0.66	0.16	6.6	0.07	1.0	1.0	10^7	5	0.66	0.66	0.16	6.6	0.07	1.0	1.0	10^7
	E-06 REMOTE MEASURING – MASS, DIMENSIONS			●			●		●	●	●			○	1	1.64	0.66	0.66	11	0.71	0.1	0.1	10^2	1	1.64	0.66	0.66	11	0.71	0.1	0.1	10^2
	E-07 MIXING UNIT – LIQUID/SOLID, LIQUID/LIQUID	●	○	○	●									●	2	0.33	0.66	0.33	13.2	0.07	0.1	0.1	10^1	2	0.66	0.66	0.33	22	0.14	0.1	0.1	10^1
	E-08 MIXING UNIT – LIQUID/GAS		●											●	1	0.33	0.66	0.33	11	0.07	0.05	0.05	10^1	2	0.99	0.66	0.33	26.4	0.21	0.1	0.1	10^1
	E-09 SLIP CAST INJECTION SYSTEM	○			●									○	1	0.66	0.66	0.66	11	0.35	0.1	0.1	10^1	1	0.99	0.99	0.99	22	1.06	0.1	0.1	10^1
	E-10 VIBRATOR	●	●		●									●	1	0.33	0.33	0.33	6.6	0.04	0.2	0.2	–	1	0.66	0.66	0.33	11	0.14	0.2	0.2	–
	E-11 MICROSCOPE STAGE ATTACHMENT			○			●							○	1	0.33	0.33	0.33	4.4	0.04	0.1	0.1	10^1	1	0.33	0.33	0.33	4.4	0.04	0.1	0.1	10^1
	E-12 PHOTOMETRIC DENSITOMETER							●						●	1	0.66	0.66	0.66	15.4	0.35	0.1	0.1	10^2	1	0.66	0.66	0.66	15.4	0.35	0.1	0.1	10^2
	E-13 UV MICRODENSITOMETER											●			1	0.99	0.66	0.66	22	0.35	0.1	0.1	10^2	1	0.99	0.66	0.66	22	0.35	0.1	0.1	10^2
	E-14 HOLOGRAPHIC INTERFEROMETER											●			1	1.64	0.99	0.66	22	1.06	0.1	0.1	10^2	1	1.64	0.99	0.66	22	1.06	0.1	0.1	10^2
	E-15 MODEL ZONE REFINER						●							●	1	0.99	0.16	0.16	22	0.04	1.5	0.2	10^2	1	0.99	0.16	0.16	22	0.04	1.5	0.2	10^2
	E-16 ISOTOPE TRACER COUNTER													●	1	0.99	0.49	0.49	11	0.35	0.1	0.1	10^2	11	0.99	0.49	0.49	11	0.35	0.1	0.1	10^3
	E-17 VHF POWER UNIT	○	●	●	●		●		○	●	●				1	1.97	0.66	1.31	176	1.77	6(50)	2	10^2	1	1.97	0.31	1.31	330	3.53	10(90)	4	10^2
	E-18 EXTERNAL MOLDS & CONTAINERS (SETS)	●	●		○									●	5	0.99	0.66	0.66	8.8	0.35	–	–	–	15	0.99	0.66	0.66	8.8	0.35	–	–	–
	E-19 MINOR EXTERNAL COMPONENTS (SETS)	●	●	○	○	○	○	○	○	○	○			●	2	0.99	0.99	0.66	22	0.71	–	–	–	4	0.99	0.99	0.99	22	0.71	–	–	–
	TOTAL REQUIREMENTS – EXTERNAL UNITS														28				705	17.6	13	7.60		45				1240	30.8	20.65	13.25	
SUPPORT UNITS	S-01 PROCESS CONTROL COMPUTER	○	●	●	○	○	●	●	○	●	●			○	1	3.94	1.97	1.97	132	15.9	0.5	0.5	10^5	1	3.94	1.97	1.97	132	15.9	0.5	0.5	10^5
	S-02 HEAT REJECTION SYSTEM	●	●	●	●	●	●	●	●	●	●	●	○	○	1	1.64	13.1	13.1	440	282	0.5	0.5	10^1	1	1.31	24.6	24.6	990	530	1	1	10^1
	S-03 CLEANUP AND REFURBISHMENT EQUIPMENT	●	●	●	●	●	●	○	○	●	●	○	○	○	1	3.28	1.64	1.64	26.4	8.85	0.25	0.25	–	1	3.28	1.64	1.64	26.4	8.85	0.25	0.25	–
	S-04 MATERIALS ANALYSIS EQUIPMENT	●	●	●	●	●	●	●	●	○	○	●		●	1	6.56	4.92	3.28	176	106	1	0.2	–	1	9.85	4.92	3.94	264	177	1	0.3	–
	S-05 PHOTOGRAPHIC PROCESSING LABORATORY	○	●	●	○	○	●	●	○	○	○	○		●	1	4.92	3.28	2.3	99	35.3	1	0.3	–	1	6.56	4.92	1.97	176	63.8	1	0.5	–
	S-06 OPEN MATERIALS & FLUIDS STORAGE	●	●	●	●	●	●	●	●	●	●			●	1	4.92	3.28	2.62	176	42.5	–	–	–	1	8.2	3.28	3.28	352	88.5	–	–	–
	S-07 CONTROLLED ATMOSPHERE FLUIDS STORAGE		○							●	●	●	●	○	1	4.92	3.28	2.62	132	28.2	–	–	–	1	4.92	4.92	3.94	220	53	–	–	–
	S-08 ACCIDENT CONTROL SYSTEM	○	○	●	○	●	●	○	○	●	●	○	○	○	1	3.28	1.64	1.64	44	17.7	0.5	–	–	1	3.28	1.64	1.64	55	8.85	0.5	–	–
	TOTAL REQUIREMENTS – SUPPORT UNITS														8				1230	529	3.75	1.75		8				2220	945	4.25	2.55	
	GRAND TOTAL, ALL EQUIPMENT														84				4740	789	94.65	44.47		124				8080	1347	157.1	77.04	

B

CREW REQUIREMENTS		1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4A	4B	5A
SKILLS	C-01 BIOLOGICAL TECHNICIAN											●	●	
	C-03 BIOCHEMIST											○	○	
	C-06 PHYSICIST				○				○	○				○
	C-08 PHOTO TECHNICIAN	○	○	○		○	○	○	○			○		○
	C-10 ELECTRONIC ENGINEER	○	○	○	○	○	○	○	○	○	○	○	○	○
	C-12 ELECTROMECHANICAL TECHNICIAN	●	●	●	●	●	●	●	●	●	●	○	○	●
	C-14 OPTICAL TECHNICIAN		○	○		○	○	○	○	○	○	○		○
	C-15 OPTICAL SCIENTIST					○	○			○	○			
	C-23 METALLURGIST	●	●	●	●		●	●	●					
	C-24 MATERIALS SCIENTIST	●	●	●	●	●	●	●	●	●	●			●
	C-25 PHYSICAL CHEMIST					○	○	○	○					○

C

PERFORMANCE REQUIREMENTS			1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4A	4B	5A
GENERAL DATA	P-01 ACCELERATION LEVEL (max.)	(ZERO-G ±)	10^{-3}	10^{-3}	10^{-4}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-4}	10^{-4}	10^{-4}	–	10^{-4}
	P-02 TIME AT LEVEL P-01	(hrs)	2.5	1.5	1	2	8	3	4	20	2	2	6.5	–	2
	P-03 POWER – PEAK (in excess of P-05)	(kW)	(5)	(4)	(10)	(5)	(9)	(10)	(5)	(7)	(50)	(84)	(3)	(2)	2
	P-04 TIME AT PEAK POWER P-03	(hrs)	0.5	0.5	0.35	0.5	0.5	0.5	0.5	20X 0.1	0.1	0.1	0.3	0.5	0.4
	P-05 POWER – SUSTAINED	(kW)	3	3	(5)	3	1.5	2	2.2	1.5	(5)	(5)	2.5	2	0.2
	P-06 TIME AT P-05 (total power time)	(hrs)	2.5	2.5	1.5	2.2	7	2.5	2.5	20	2.6	2.6	6	2	2
	P-07 DIGITAL DATA TRANSMISSION	(BPS)	10^2	10^2	10^4	10^2	10^4	10^4	10^4	10^4	10^4	10^5	10^4	10^4	10^4
RUNS	P-08 NUMBER OF RUNS/YEAR	MINIMUM	24	16	16	12	12	26	20	20	12	6	40	40	40
	P-09	DESIRABLE	60	40	50	28	26	72	40	60	40	24	200	200	150
DATA PER RUN	P-10 PERFORMANCE TIME/RUN	(hrs)	9	8.5	7.5	8	14	8.5	9	25	10	10	8.5	3	4
	P-11 POWER INPUT/RUN	(kWh)	10	9.5	11	9	15	10	8	44	18	24	16	5	1.2
	P-12 HEAT LOAD/RUN	(kCal)	8,500	8,000	9,400	7,700	12,800	8,500	6,800	37,500	15,400	20,400	13,700	4,300	1,000
	P-13 MATERIALS/RUN – WEIGHT	(lb)	6.6	2.2	4.4	6.6	2.2	1.1	1.1	1.1	0.22	0.66	13.2	8.8	0.44
	P-14 MATERIALS/RUN – VOLUME	(in^3)	36.6	183	24.4	61	15.25	14.64	61	14.64	2.14	6.1	366	244	15.25
	P-15 WASTE MATERIAL/RUN – WEIGHT	(lb)	2.2	1.1	–	2.2	4.4	–	–	–	–	–	4.4	4.4	0.44
	P-16 WASTE MATERIAL/RUN – VOLUME	(in^3)	12.2	6.1	–	36.6	61	–	–	–	–	–	122	122	15.25
	P-17 LOGISTICS/RUN-UP – WEIGHT	(lb)	6.6	2.2	4.4	6.6	6.6	4.4	1.1	4.4	0.22	0.66	22	–	0.44
	P-18 LOGISTICS/RUN-UP – VOLUME	(in^3)	36.6	12.2	24.4	61	91.6	14.64	61	14.64	2.14	6.1	366	–	15.25
	P-19 LOGISTICS/RUN – RETURN – WEIGHT	(lb)	4.4	1.1	4.4	4.4	2.2	4.4	1.1	4.4	0.22	0.66	–	13.2	–
	P-20 LOGISTICS/RUN – RETURN – VOLUME	(in^3)	24.4	91.5	24.4	24.4	30.5	14.64	61	14.64	2.14	6.1	–	122	–
	P-21 CREW TIME/RUN – 1 MAN	(hrs)	5	4	4	4	6	6	5	6	4	6	–	–	3
	P-22 CREW TIME/RUN - 2 MAN (Σ)	(hrs)	3	4	5	3	4	5	4	4	6	6	3	1	–
	P-23 CREW TIME/RUN – OTHERS (Σ)	(hrs)	2	2	3	2	2	2	2	2	3	3	–	–	1
	P-24 DATA TRANSM. P-07 TIME/RUN – PEAK	(hrs)	5	3	4	5	20	5	10	100	6	8	20	4	4
	P-25 DATA TRANSM. P-07 TIME/RUN – AVERAGE	(hrs)	3	1	2	3	12	3	4	20	4	4	8	2	1
	P-26 TV/VOICE TRANSM. TIME/RUN – DIRECT	(hrs)	1	1	2	2	1	2	–	–	3	4	1	–	–
	P-27 TV/VOICE – STORED - REPLAY TO GROUND	(hrs)	2	3	4	3	6	4	3	8	4	6	6	2	2

LEGEND

EXPERIMENT CLASSES	
1A	METAL MATRIX COMPOSITES
1B	CONTROLLED DENSITY MATERIALS (METAL FOAMS)
1C	FREE CASTING OF METALS
1D	LIQUID DISPERSIONS
2A	CRYSTAL GROWTH FROM SOLUTION
2B	CRYSTAL GROWTH FROM MELT
2C	CRYSTAL GROWTH FROM VAPOR
2D	SUPERCOOLING & HOMOGENEOUS NUCLEATION
3A	PREPARATION OF GLASSES
3B	GLASS PROCESSING
4A	BIOLOGICAL SEPARATION
4B	PRESERVATION OF BIOCHEMICALS
5	PHYSICAL PROCESSES IN FLUIDS

BLOCK A-2

● *PRIMARY OR MANDATORY APPLICATION*

○ OPTIONAL OR OCCASIONAL USE

BLOCK A-3:

DIMENSIONS REPRESENT AN APPROXIMATE ENVELOPE RATHER THAN EXACT CONFIGURATION. DATA FOR WEIGHT AND VOLUME ARE BASED ON ACTUAL CONFIGURATION. POWER DATA REPRESENT INSTALLED CAPABILITY; POWER TOTALS ARE, THEREFORE, INSTALLED TOTALS AND NOT TOTAL CONSUMPTION.

UNITS IDENTIFIED AS "SETS" (I-04, I-22, I 23, E-18, E-19) COMPRISE INDIVIDUAL COMPONENTS OF VARIED CONFIGURATIONS, USED SELECTIVELY FOR SPECIFIC EXPERIMENTS; DATA IN BLOCK A-3 REPRESENT ONE COMPLETE SET.

() POWER DATA IN PARENTHESES REPRESENT BATTERY OR BATTERY SUPPLEMENTED POWER. STORED BATTERY POWER IS NOT INCLUDED IN THE POWER DATA FOR UNIT B-10.

BLOCK B-2

● PRINCIPAL FUNCTION

○ SUPPORTING FUNCTION

BLOCK C-2

PERFORMANCE DATA REPRESENT AVERAGES FOR EXPERIMENT CLASS, UNLESS DEFINED OTHERWISE, EXCLUDING REQUIREMENTS FOR SUPPORT ACTIVITIES AND SUPPORT UNITS. THEY ARE BASED ON SELECTIVE USE OF EQUIPMENT IDENTIFIED FOR EACH CLASS IN BLOCK A-2 AND ON THE MOST TYPICAL PERFORMANCE LEVELS.

POWER DATA IN PARENTHESES () REPRESENT BATTERY OR BATTERY SUPPLEMENTED POWER. POWER VALUES DO NOT INCLUDE POWER FOR SUPPORT EQUIPMENT, BATTERY CHARGING, ETC. OF 2 kW CONTINUOUS. FOR FURTHER DEFINITION OF POWER DESCRIPTORS IN BLOCK C-1, SEE FIGURE 1-7, SECTION 1.5.

PERFORMANCE TIME P-10 AND CREW TIME P-21, P-22, P-23 INCLUDE EXPERIMENT SETUP, MATERIAL HANDLING, AND EVALUATION.

TABLE 1-2. MS/MS EXPERIMENT REQUIREMENTS SUMMARY

(SI UNITS)

1 — REQUIREMENTS

2 — EXPERIMENT CLASSES

3 — EQUIPMENT DATA

EQUIPMENT UNITS		2: 1 METALLURGICAL 1A	1B	1C	1D	2 CRYSTAL GROWTH 2A	2B	2C	2D	3 GLASSES 3A	3B	4 BIOLOG. 4A	4B	5 PHYS. 5A	3: MINIMUM CAPABILITY QTY. EACH	DIMENSIONS (m) X	Y	Z	MASS (kg)	VOL. (m^3)	POWER (kw) MAX.	SUST.	DIG. DATA BPS	DESIRABLE CAPABILITY QTY. EACH	DIMENSIONS (m) X	Y	MASS (kg)	VOL. (m^3)	POWER (kw) MAX.	SUST.	DIG. DATA BPS	
BASIC UNITS	B-01 CONTROLLED ATMOSPHERE CHAMBER			●			○	○	●					○	1	2.0	0.8	0.8	150	0.9	1.0	0.1	10^1	1	2.4	1.0	1.0	210	1.7	1.0	0.1	10^1
	B-02 ENVIRONMENTAL CHAMBER 'A' – PASSIVE COOLING	●	●	●	●	○	●			○	○				1	1.1	0.7	0.7	60	0.5	1.0	0.2	10^1	1	1.4	0.9	0.9	120	1.1	1.0	0.4	10^2
	B-03 ENVIRONMENTAL CHAMBER 'B' – PASSIVE COOLING	●	●	●	●	●	●	●	●					●	1	0.8	0.5	0.5	30	0.2	0.5	0.1	10^1	2	0.8	0.5	0.5	30	0.2	0.5	0.1	10^1
	B-04 ENVIRONMENTAL CHAMBER 'C' – ACTIVE COOLING	○	○	●	○		○	○	○	●	●			○	1	0.8	0.5	0.5	45	0.2	0.7	0.2	10^2	1	0.8	0.5	0.5	45	0.2	0.7	0.2	10^2
	B-05 BIOLOGICAL ENCLOSURE											●	●		1	1.5	0.9	1.2	204	1.5	2.1	1.8	10^2	1	1.5	0.9	1.2	204	1.5	2.1	1.8	10^2
	B-06 LIQUID METAL SUPPLY SYSTEM	●	●	●	○										1	0.4	0.3	0.25	15	0.05	0.8	0.3	10^2	2	0.5	0.4	0.4	25	0.1	1.5	0.5	10^2
	B-07 GENERAL PURPOSE LABORATORY INSTALLATION	○	●		○	●	○	○				●		●	1	1.2	1.5	0.6	40	1.0	1.5	0.3	10^3	1	1.6	1.5	0.6	50	1.2	1.5	0.3	10^3
	B-08 INSTRUMENTATION AND CONTROL CENTER	●	●	●	●	●	●	●	●	●	●	●	●	○	1	1.5	1.0	1.0	120	1.5	0.5	0.3	10^4	1	1.5	1.5	1.0	150	2.2	0.7	0.3	10^5
	B-09 ATMOSPHERE SUPPLY & CONTROL SYSTEM	●	●	●	○	○	●	○	●	●	●			●	1	0.7	0.6	0.4	70	0.2	1	0.3	10^2	1	1.0	0.6	0.05	100	0.3	1	0.3	10^2
	B-10 POWER CONDITIONING & DISTRIBUTION SYSTEM	●	●	●	●	●	●	●	●	●	●	●	●	●	1	1.0	0.5	0.5	210	0.25	14(50)	9	10^2	1	1.2	0.6	0.5	380	0.35	21(90)	12	10^2
	TOTAL REQUIREMENTS – BASIC UNITS														10				944	6.3	23.1	12.6		12				1369	9.15	33	16.6	
INTERNAL UNITS	I-01 RESISTANCE HEATED FURNACE – 1600°C	●	●	●	●	●		●						○	2	0.4	0.2	0.2	10	0.02	4	1.2	10^1	2	0.5	0.3	0.3	18	0.04	6	2	10^1
	I-02 FURNACE – 2600°C – INERT/VACUUM			●	○			○		○	○				1	0.4	0.2	0.2	18	0.02	7	3	10^1	1	0.5	0.3	0.3	30	0.04	9	4	10^1
	I-03 FURNACE – 3200°C – OXYGEN									●	●				1	0.3	0.3	0.3	26	0.02	9(50)	6	10^2	1	0.4	0.4	0.4	45	0.05	14(90)	8	10^2
	I-04 HEATING AND POSITIONING COILS (SETS)			●			○		○	●	●				3	0.2	0.2	0.2	12	0.01	6(15)	2	10^2	5	0.3	0.3	0.3	20	0.04	10(30)	4	10^2
	I-05 PLASMA ELECTRON BEAM UNIT			●						●	●				1	0.2	0.1	0.1	4	0.002	5	2	10^1	1	0.2	0.1	0.1	4	0.002	–	2	10^1
	I-06 MOLD INJECTION SYSTEM	●	●		●										1	0.1	0.1	0.1	3	0.001	–	–	10^1	1	0.15	0.15	0.15	6	0.004	–	–	10^1
	I-07 DISPERSION CONTROL SYSTEM	●	●	○	●									○	1	0.25	0.25	0.25	5	0.02	–	–	10^1	1	0.4	0.4	0.4	15	0.07	1	1	10^2
	I-08 LIQUID SPHERE DEPLOYMENT SYSTEM			●											1	0.1	0.1	0.1	3	0.001	0.1	–	10^1	2	0.1	0.15	0.15	4	0.002	0.1	–	10^1
	I-09 HOLLOW BODIES DEPLOYMENT SYSTEM			●											1	0.2	0.1	0.1	4	0.002	0.2	–	10^1	1	0.2	0.15	0.15	6	0.004	0.2	–	10^1
	I-10 MEMBRANE DRAWING TOOL			●											1	0.3	0.2	0.1	4	0.006	0.1	0.1	10^1	2	0.5	0.2	0.2	7	0.02	0.2	0.2	10^1
	I-11 ZONE MELTER						●								1	0.3	0.15	0.15	8	0.007	0.2	0.1	10^2	1	0.5	0.15	0.15	9	0.01	0.2	0.1	10^2
	I-12 CZOCHRALSKI CRYSTAL PULLER						●								1	0.5	0.2	0.2	12	0.02	0.2	0.1	10^2	2	0.5	0.2	0.2	12	0.02	0.2	0.1	10^2
	I-13 SUSCEPTOR FOR SILICATE MELTS					●									1	0.1	0.05	0.05	1	0.001	0.2	0.1	10^2	2	0.2	0.1	0.1	2	0.002	0.2	0.1	10^2
	I-14 HIGH TEMPERATURE CALORIMETER								●						1	0.2	0.1	0.1	7	0.002	2	0.5	10^3	1	0.2	0.1	0.1	7	0.002	2	0.5	10^3
	I-15 SEED INJECTOR					●									2	0.1	0.03	0.03	1	10^{-4}	0.05	0.05	10^1	2	0.1	0.03	0.03	1	10^{-4}	0.05	0.05	10^1
	I-16 INTERNAL FRICTION MEASURING DEVICE								●						1	0.1	0.05	0.05	4	10^{-4}	0.1	0.1	10^3	1	0.1	0.05	0.05	4	10^{-4}	0.1	0.1	10^3
	I-17 STATIONARY ELECTROPHORETIC COLUMN											●			2	0.3	0.3	0.02	10	0.002	0.2	0.02	10^2	4	0.3	0.3	0.02	10	0.002	0.2	0.02	10^2
	I-18 CONTINUOUS ELECTROPHORETIC COLUMN											●			2	0.3	0.45	0.2	20	0.03	0.4	0.09	10^2	4	0.3	0.45	0.2	20	0.03	0.4	0.09	10^2
	I-19 BUFFER RECOVERY/WASTE DISPOSAL SYSTEM											●			2	0.5	0.3	0.3	20	0.05	1	0.2	10^1	4	0.5	0.3	0.3	20	0.05	1	0.2	10^1
	I-20 GAS ELIMINATION/COOLING SYSTEM											●			2	0.5	0.2	0.2	10	0.02	0.5	0.5	10^1	4	0.5	0.2	0.2	10	0.02	0.5	0.5	10^1
	I-21 LYPHOLIZATION APPARATUS												●		1	0.25	0.2	0.2	10	0.01	0.4	0.4	10^1	2	0.25	0.2	0.2	10	0.01	0.4	0.4	10^1
	I-22 MOLDS, CAVITIES, CRUCIBLES (SETS)	●	●		●	●		○						●	5	0.3	0.3	0.2	5	0.02	–	–	–	10	0.5	0.3	0.2	7	0.03	–	–	–
	I-23 MISCELLANEOUS INTERNAL ATTACHMENTS (SETS)	●	●	●	○	○	●	○	○	○	○				4	0.2	0.2	0.2	5	0.01	–	–	–	5	0.3	0.3	0.2	10	0.02	–	–	–
	TOTAL REQUIREMENTS – INTERNAL UNITS														38				333	0.526	54.8	22.52		59				744	1.378	99.2	44.64	
EXTERNAL UNITS	E-01 CONTINUOUS ATMOSPHERE ANALYSIS APPARATUS			○			○		●	●	●				1	0.75	0.5	0.5	90	0.2	0.15	0.15	10^3	1	0.75	0.5	0.5	90	0.2	0.15	0.15	10^3
	E-02 HIGH TEMPERATURE VIEWING DEVICE			○			○		○	●	●				1	0.5	0.2	0.2	5	0.02	0.1	0.1	10^2	1	0.5	0.2	0.2	5	0.02	0.1	0.1	10^2
	E-03 CHILL SYSTEM	○	○	○	●										1	0.4	0.2	0.2	6	0.02	0.1	–	–	1	0.6	0.3	0.3	10	0.06	0.1	–	–
	E-04 MOTION PICTURE CAMERA			●		○	●	●						●	2	0.3	0.2	0.1	8	0.006	0.5	0.5	10^1	3	0.3	0.2	0.1	8	0.006	0.5	0.5	10^1
	E-05 TV CAMERA		○	●		○	●	●	○			●		●	3	0.2	0.2	0.05	3	0.002	1.0	1.0	10^7	5	0.2	0.2	0.05	3	0.002	1.0	1.0	10^7
	E-06 REMOTE MEASURING – MASS, DIMENSIONS			●			●		●	●	●			○	1	0.5	0.2	0.2	5	0.02	0.1	0.1	10^2	1	0.5	0.2	0.2	5	0.02	0.1	0.1	10^2
	E-07 MIXING UNIT – LIQUID/SOLID, LIQUID/LIQUID	●	○	○	●									●	2	0.1	0.2	0.1	6	0.002	0.1	0.1	10^1	2	0.2	0.2	0.1	10	0.004	0.1	0.1	10^1
	E-08 MIXING UNIT – LIQUID/GAS		●											●	1	0.1	0.2	0.1	5	0.002	0.05	0.05	10^1	2	0.3	0.2	0.1	12	0.006	0.1	0.1	10^1
	E-09 SLIP CAST INJECTION SYSTEM	○			●									○	1	0.2	0.2	0.2	5	0.01	0.1	0.1	10^1	1	0.3	0.3	0.3	10	0.03	0.1	0.1	10^1
	E-10 VIBRATOR	●	●		●									●	1	0.1	0.1	0.1	3	0.001	0.2	0.2	–	1	0.2	0.2	0.1	5	0.004	0.2	0.2	–
	E-11 MICROSCOPE STAGE ATTACHMENT			○			●							○	1	0.1	0.1	0.1	2	0.001	0.1	0.1	10^1	1	0.1	0.1	0.1	2	0.001	0.1	0.1	10^1
	E-12 PHOTOMETRIC DENSITOMETER							●						●	1	0.2	0.2	0.2	7	0.01	0.1	0.1	10^2	1	0.2	0.2	0.2	7	0.01	0.1	0.1	10^2
	E-13 UV MICRODENSITOMETER											●			1	0.3	0.2	0.2	10	0.01	0.1	0.1	10^2	1	0.3	0.2	0.2	10	0.01	0.1	0.1	10^2
	E-14 HOLOGRAPHIC INTERFEROMETER											●			1	0.5	0.3	0.2	10	0.03	0.1	0.1	10^2	1	0.5	0.3	0.2	10	0.03	0.1	0.1	10^2
	E-15 MODEL ZONE REFINER						●							●	1	0.3	0.05	0.05	10	0.001	1.5	0.2	10^2	1	0.3	0.05	0.05	10	0.001	1.5	0.2	10^2
	E-16 ISOTOPE TRACER COUNTER													●	1	0.3	0.15	0.15	5	0.01	0.1	0.1	10^2	11	0.3	0.15	0.15	5	0.01	0.1	0.1	10^3
	E-17 VHF POWER UNIT	○	●	●	●		●		○	●	●				1	0.6	0.2	0.4	80	0.05	6(50)	2	10^2	1	0.6	0.4	0.4	150	0.1	10(90)	4	10^2
	E-18 EXTERNAL MOLDS & CONTAINERS (SETS)	●	●		○									●	5	0.3	0.2	0.2	4	0.01	–	–	–	15	0.3	0.2	0.2	4	0.01	–	–	–
	E-19 MINOR EXTERNAL COMPONENTS (SETS)	●	●	○	○	○	○	○	○	○	○			●	2	0.3	0.3	0.2	10	0.02	–	–	–	4	0.3	0.3	0.2	10	0.02	–	–	–
	TOTAL REQUIREMENTS – EXTERNAL UNITS														28				320	0.497	13	7.60		45				552	0.874	20.65	13.25	
SUPPORT UNITS	S-01 PROCESS CONTROL COMPUTER	○	●	●	○	○	●	●	○	●	●			○	1	1.2	0.6	0.6	60	0.45	0.5	0.5	10^5	1	1.2	0.6	0.6	60	0.45	0.5	0.5	10^5
	S-02 HEAT REJECTION SYSTEM	●	●	●	●	●	●	●	●	●	●	●	○	○	1	0.5	4.0	4.0	200	8	0.5	0.5	10^1	1	0.4	7.5	7.5	450	15	1	1	10^1
	S-03 CLEANUP AND REFURBISHMENT EQUIPMENT	●	●	●	●	●	●	○	○	●	●	○	○	○	1	1.0	0.5	0.5	12	0.25	0.25	0.25	–	1	1.0	0.5	0.5	12	0.25	0.25	0.25	–
	S-04 MATERIALS ANALYSIS EQUIPMENT	●	●	●	●	●	●	●	●	○	○	●		●	1	2.0	1.5	1	80	3.0	1	0.2	–	1	3	1.5	1.2	120	5.0	1	0.3	–
	S-05 PHOTOGRAPHIC PROCESSING LABORATORY	○	●	●	○	○	●	●	○	○	○	○		●	1	1.5	1	0.7	45	1	1	0.3	–	1	2	1.5	0.6	80	1.8	1	0.5	–
	S-06 OPEN MATERIALS & FLUIDS STORAGE	●	●	●	●	●	●	●	●	●	●			●	1	1.5	1	0.8	80	1.2	–	–	–	1	2.5	1	1	160	2.5	–	–	–
	S-07 CONTROLLED ATMOSPHERE FLUIDS STORAGE		○							●	●	●	●	○	1	1.5	1	0.8	60	0.8	–	–	–	1	1.5	1.5	1.2	100	1.5	–	–	–
	S-08 ACCIDENT CONTROL SYSTEM	○	○	●	○	●	●	○	○	●	●	○	○	○	1	1.0	0.5	0.5	20	0.25	0.5	–	–	1	1.0	0.5	0.5	25	0.25	0.5	–	–
	TOTAL REQUIREMENTS – SUPPORT UNITS														8				557	14.95	3.75	1.75		8				1007	26.75	4.25	2.55	
	GRAND TOTAL, ALL EQUIPMENT														84				2154	22.273	94.65	44.47		124				3672	38.152	157.1	77.04	

B

CREW REQUIREMENTS		1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4A	4B	5A
SKILLS	C-01 BIOLOGICAL TECHNICIAN											●	●	
	C-03 BIOCHEMIST											○	○	
	C-06 PHYSICIST				○				○	○				○
	C-08 PHOTO TECHNICIAN	○	○	○		○	○	○	○			○		○
	C-10 ELECTRONIC ENGINEER	○	○	○	○	○	○	○	○	○	○	○	○	○
	C-12 ELECTROMECHANICAL TECHNICIAN	●	●	●	●	●	●	●	●	●	●	○	○	●
	C-14 OPTICAL TECHNICIAN		○	○		○	○	○	○	○	○	○		○
	C-15 OPTICAL SCIENTIST					○	○			○	○			
	C-23 METALLURGIST	●	●	●	●		●	●	●					
	C-24 MATERIALS SCIENTIST	●	●	●	●	●	●	●	●	●	●			●
	C-25 PHYSICAL CHEMIST					○	○	○	○					○

C

PERFORMANCE REQUIREMENTS			1A	1B	1C	1D	2A	2B	2C	2D	3A	3B	4A	4B	5A
GENERAL DATA	P-01 ACCELERATION LEVEL (max.)	(ZERO-G ±)	10^{-3}	10^{-3}	10^{-4}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-4}	10^{-4}	10^{-4}	–	10^{-4}
	P-02 TIME AT LEVEL P-01	(hrs)	2.5	1.5	1	2	8	3	4	20	2	2	6.5	–	2
	P-03 POWER – PEAK (in excess of P-05)	(kW)	(5)	(4)	(10)	(5)	(9)	(10)	(5)	(7)	(50)	(84)	(3)	(2)	2
	P-04 TIME AT PEAK POWER P-03	(hrs)	0.5	0.5	0.35	0.5	0.5	0.5	0.5	20X 0.1	0.1	0.1	0.3	0.5	0.4
	P-05 POWER – SUSTAINED	(kW)	3	3	(5)	3	1.5	2	2.2	1.5	(5)	(6)	2.5	2	0.2
	P-06 TIME AT P-05 (total power time)	(hrs)	2.5	2.5	1.5	2.2	7	2.5	2.5	20	2.6	2.6	6	2	2
	P-07 DIGITAL DATA TRANSMISSION	(BPS)	10^2	10^2	10^4	10^2	10^4	10^4	10^4	10^4	10^4	10^5	10^4	10^4	10^4
RUNS	P-08 NUMBER OF RUNS/YEAR	MINIMUM	24	16	16	12	12	26	20	20	12	6	40	40	40
	P-09	DESIRABLE	60	40	50	28	26	72	40	60	40	24	200	200	150
DATA PER RUN	P-10 PERFORMANCE TIME/RUN	(hrs)	9	8.5	7.5	8	14	8.5	9	25	10	10	8.5	3	4
	P-11 POWER INPUT/RUN	(kWh)	10	9.5	11	9	15	10	8	44	18	24	16	5	1.2
	P-12 HEAT LOAD/RUN	(MJ)	35.6	33.5	39.4	32.2	53.6	35.6	28.4	157	64.5	85.5	57.5	18	4.19
	P-13 MATERIALS/RUN – MASS	(kg)	3	1	2	3	1	0.5	0.5	0.5	0.1	0.3	6	4	0.2
	P-14 MATERIALS/RUN – VOLUME	(cm^3)	600	3,000	400	1,000	250	240	1,000	240	35	100	6,000	4,000	250
	P-15 WASTE MATERIAL/RUN – MASS	(kg)	1	0.5	–	1	2	–	–	–	–	–	2	2	0.2
	P-16 WASTE MATERIAL/RUN – VOLUME	(cm^3)	200	100	–	600	1,000	–	–	–	–	–	2,000	2,000	250
	P-17 LOGISTICS/RUN-UP – MASS	(kg)	3	1	2	3	3	2	0.5	2	0.1	0.3	10	–	0.2
	P-18 LOGISTICS/RUN-UP – VOLUME	(cm^3)	600	200	400	1,000	1,500	240	1,000	240	35	100	6,000	–	250
	P-19 LOGISTICS/RUN – RETURN – MASS	(kg)	2	0.5	2	2	1	2	0.5	2	0.1	0.3	–	6	–
	P-20 LOGISTICS/RUN – RETURN – VOLUME	(cm^3)	400	1,500	400	400	500	240	1,000	240	35	100	–	2,000	–
	P-21 CREW TIME/RUN – 1 MAN	(hrs)	5	4	4	4	6	6	5	6	4	6	–	–	3
	P-22 CREW TIME/RUN - 2 MAN (Σ)	(hrs)	3	4	5	3	4	5	4	4	6	6	3	1	–
	P-23 CREW TIME/RUN – OTHERS (Σ)	(hrs)	2	2	3	2	2	2	2	2	3	3	–	–	1
	P-24 DATA TRANSM. P-07 TIME/RUN – PEAK	(hrs)	5	3	4	5	20	5	10	100	6	8	20	4	4
	P-25 DATA TRANSM. P-07 TIME/RUN – AVERAGE	(hrs)	3	1	2	3	12	3	4	20	4	4	8	2	1
	P-26 TV/VOICE TRANSM. TIME/RUN – DIRECT	(hrs)	1	1	2	2	1	2	–	–	3	4	1	–	–
	P-27 TV/VOICE – STORED REPLAY TO GROUND	(hrs)	2	3	4	3	6	4	3	8	4	6	6	2	2

LEGEND

EXPERIMENT CLASSES	
1A	METAL MATRIX COMPOSITES
1B	CONTROLLED DENSITY MATERIALS (METAL FOAMS)
1C	FREE CASTING OF METALS
1D	LIQUID DISPERSIONS
2A	CRYSTAL GROWTH FROM SOLUTION
2B	CRYSTAL GROWTH FROM MELT
2C	CRYSTAL GROWTH FROM VAPOR
2D	SUPERCOOLING & HOMOGENEOUS NUCLEATION
3A	PREPARATION OF GLASSES
3B	GLASS PROCESSING
4A	BIOLOGICAL SEPARATION
4B	PRESERVATION OF BIOCHEMICALS
5	PHYSICAL PROCESSES IN FLUIDS

BLOCK A-2

● PRIMARY OR MANDATORY APPLICATION

○ OPTIONAL OR OCCASIONAL USE

BLOCK A-3:

DIMENSIONS REPRESENT AN APPROXIMATE ENVELOPE RATHER THAN EXACT CONFIGURATION. DATA FOR WEIGHT AND VOLUME ARE BASED ON ACTUAL CONFIGURATION. POWER DATA REPRESENT INSTALLED CAPABILITY; POWER TOTALS ARE, THEREFORE, INSTALLED TOTALS AND NOT TOTAL CONSUMPTION.

UNITS IDENTIFIED AS "SETS" (I-04, I-22, I-23, E-18, E-19) COMPRISE INDIVIDUAL COMPONENTS OF VARIED CONFIGURATIONS, USED SELECTIVELY FOR SPECIFIC EXPERIMENTS; DATA IN BLOCK A-3 REPRESENT ONE COMPLETE SET.

() POWER DATA IN PARENTHESES REPRESENT BATTERY OR BATTERY SUPPLEMENTED POWER. STORED BATTERY POWER IS NOT INCLUDED IN THE POWER DATA FOR UNIT B-10.

BLOCK B-2

● PRINCIPAL FUNCTION

○ SUPPORTING FUNCTION

BLOCK C-2:

PERFORMANCE DATA REPRESENT AVERAGES FOR EXPERIMENT CLASS, UNLESS DEFINED OTHERWISE, EXCLUDING REQUIREMENTS FOR SUPPORT ACTIVITIES AND SUPPORT UNITS. THEY ARE BASED ON SELECTIVE USE OF EQUIPMENT IDENTIFIED FOR EACH CLASS IN BLOCK A-2 AND ON THE MOST TYPICAL PERFORMANCE LEVELS.

POWER DATA IN PARENTHESES () REPRESENT BATTERY OR BATTERY SUPPLEMENTED POWER. POWER VALUES DO NOT INCLUDE POWER FOR SUPPORT EQUIPMENT, BATTERY CHARGING, ETC. OF 2 kW CONTINUOUS. FOR FURTHER DEFINITION OF POWER DESCRIPTORS IN BLOCK C-1, SEE FIGURE 1-7, SECTION 1.5.

PERFORMANCE TIME P-10 AND CREW TIME P-21, P-22, P-23 INCLUDE EXPERIMENT SETUP, MATERIAL HANDLING, AND EVALUATION.